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3 Reverse

TASSEL - Space Laboratory

(Three Astronaut Space System Experimental Laboratory)

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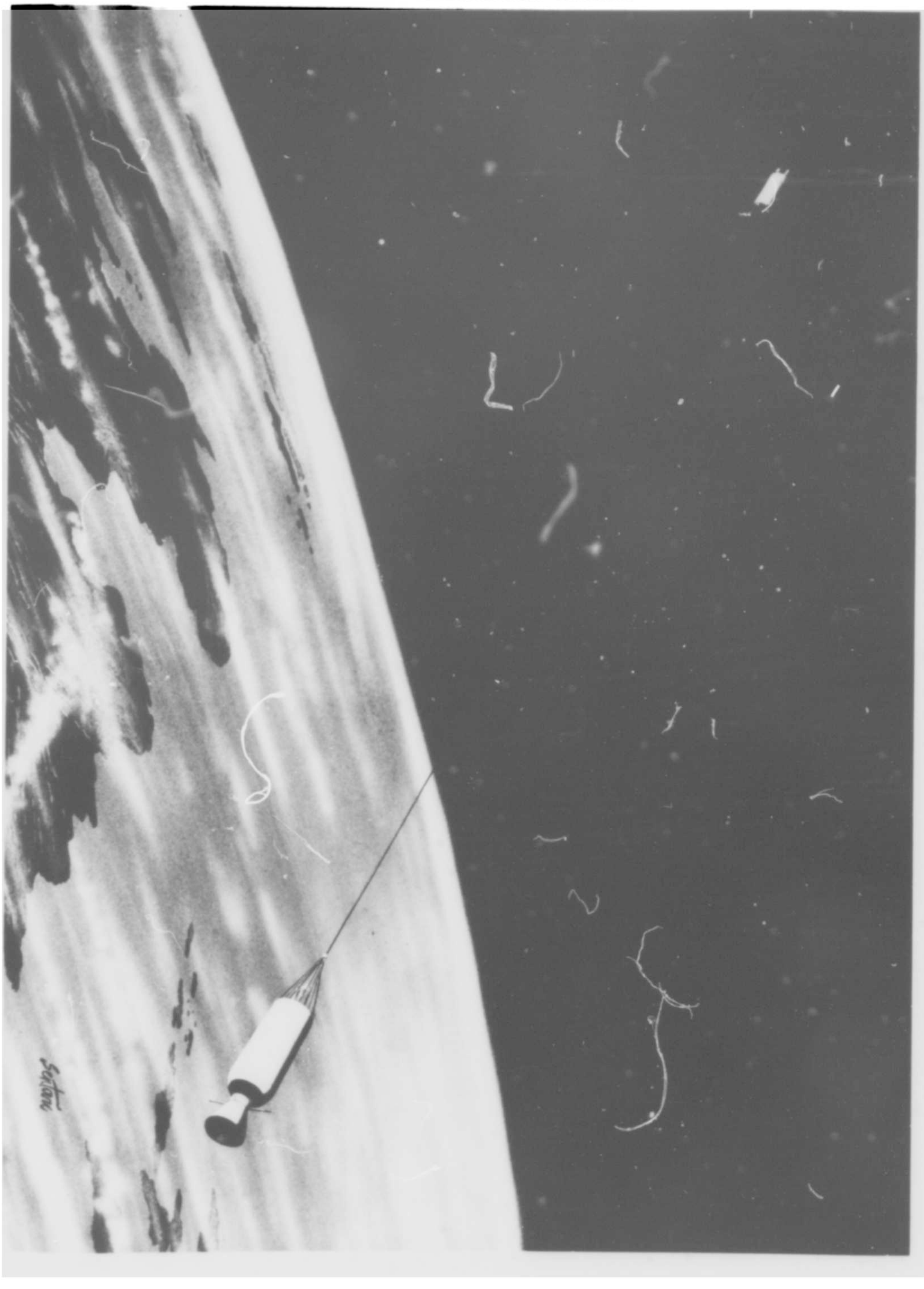
FOREWORD

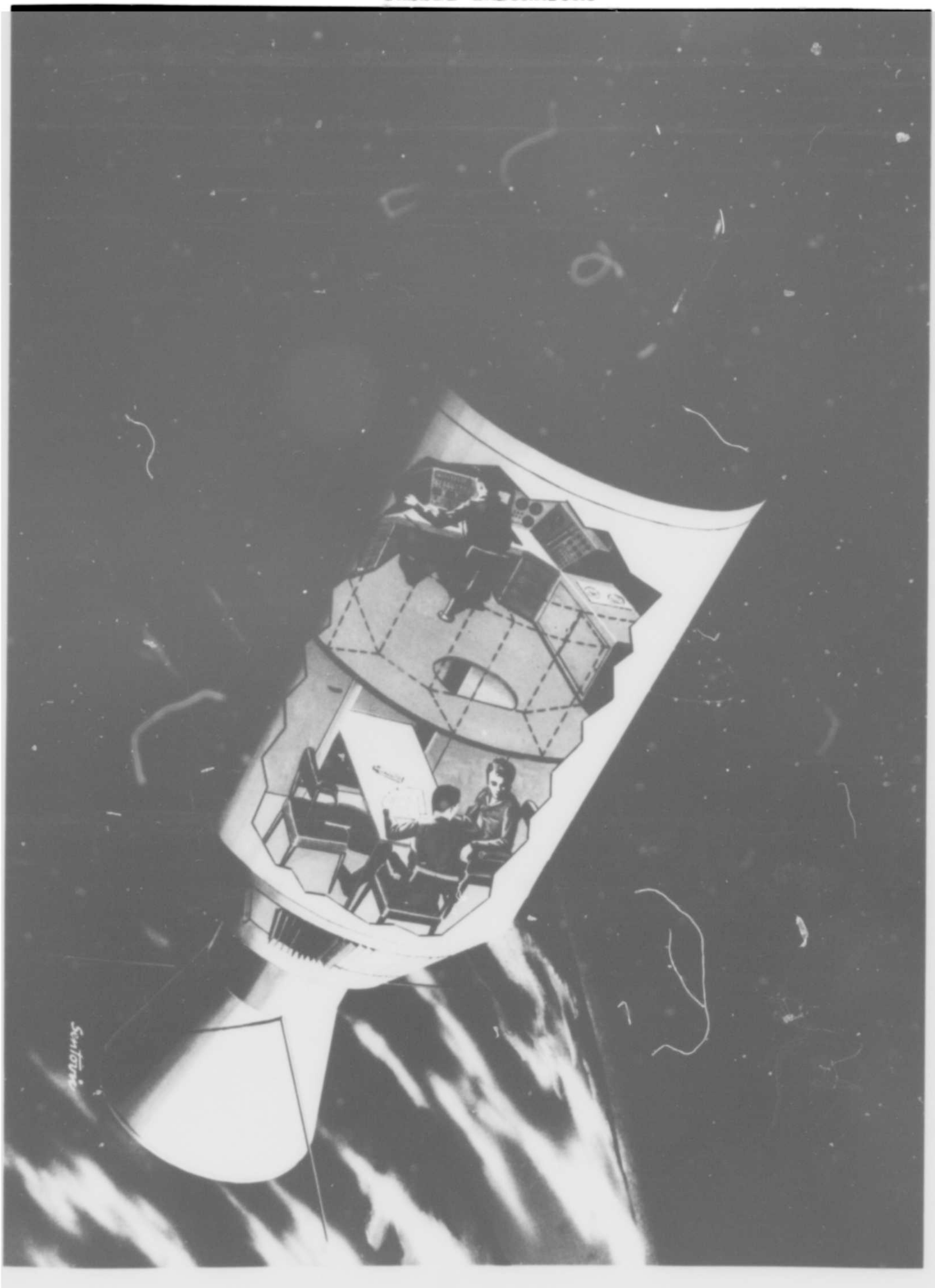
This report contains preliminary information pertaining to a Three Astronaut Space System Experimental Laboratory, "TASSEL".

Space laboratory Tassel would utilize the boost capability of Atlas/Centaur. Its purpose is primarily for conducting basic research in the biomedical and equipment evaluation sciences. Its early availability would enable it to fill the gap between the Mercury capsule experiments and the permanent space station. Beyond this period its usefulness would be limited to special short term research projects. This report is prepared under funds awarded by REA #114-9135 titled, "Advanced Space System Study". Enclosed are vehicle design parameters, capabilities and operations.

TASSEL SPACE LABORATORY SYSTEM



TASSEL LABORATORY



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INTRODUCTION

The era between the Mercury experiments and the permanent space station must be planned for a continuing program of manned orbital research. This will be necessary for the broadening of our space technologies and insuring economical optimum designs of future manned spacecraft.

The Mercury experiments will provide considerable information about man's ability to perform in a weightless environment, the functioning of his equipment and orbital control techniques. But due to limited payloads, these experiments will be confined only to a small portion of what is needed. For instance, time duration at zero or reduced gravity appears to be an important psychological and physiological parameter. One-day orbital flights with the present Mercury capsule will tell little about what man will be able to do over extended periods aloft or his physiological condition for re-entry after prolonged periods at zero or reduced gravity. They will tell little if anything about psychological or sociological effects upon individuals undergoing prolonged confinement in space.

Some of these questions can be resolved in space simulators on earth, but as these devices are not capable of complete simulation, most experiments must be made in real space environment. It is apparent, therefore, that a space laboratory must be available for

basic research by the time the Mercury's usefulness declines.

The space laboratory would have to be a flexible system, simply designed and utilizing existing technologies and hardware in order to be available in the early sixties.

The space laboratory Tassel (Three Astronaut Space System Experimental Laboratory) presented in this report provides an ideally suited system for performing the missions required of an early space laboratory. It is shown in the frontispiece in a 200 n. mi. orbit with its three-astronaut re-entry capsule attached. This laboratory would be capable of simulating any desirable level of gravitational environment. Figure 1 shows the ascent of Tassel utilizing the launch booster, Atlas-Centaur. Injection into orbit is accomplished by the Centaur stage after Atlas burnout. In orbit the depleted Centaur stage serves as a counter mass for the laboratory, thus creating artificial gravity as the cable-connected two-body system rotates about its common center of mass.

Tassel possesses certain unique advantages that permit it to become operational early in the history of manned space flight. No technological breakthroughs are required before it can perform a successful mission. For example, it does not require solution to the rendezvous problem as its cabin, cargo, earth return vehicle and the astronauts are delivered into orbit in one package. The orbit may be any one of a number requiring only relatively crude guidance

for injection. Although Tassel is limited to short-term experiments of two or three weeks, most of the fundamental problems of man inc space can be resolved during this duration. The space laboratory is a must for the economical development of all advanced manned spacecraft.

After certain technological breakthroughs are gained and large-scale undertakings in space begin, the permanent space station will be needed to train crews for long interplanetary expeditions, make long-term evaluations of space travel equipment and provide a platform for astronomical study, weather reconnaissance, orbital assembly, medical research, etc.

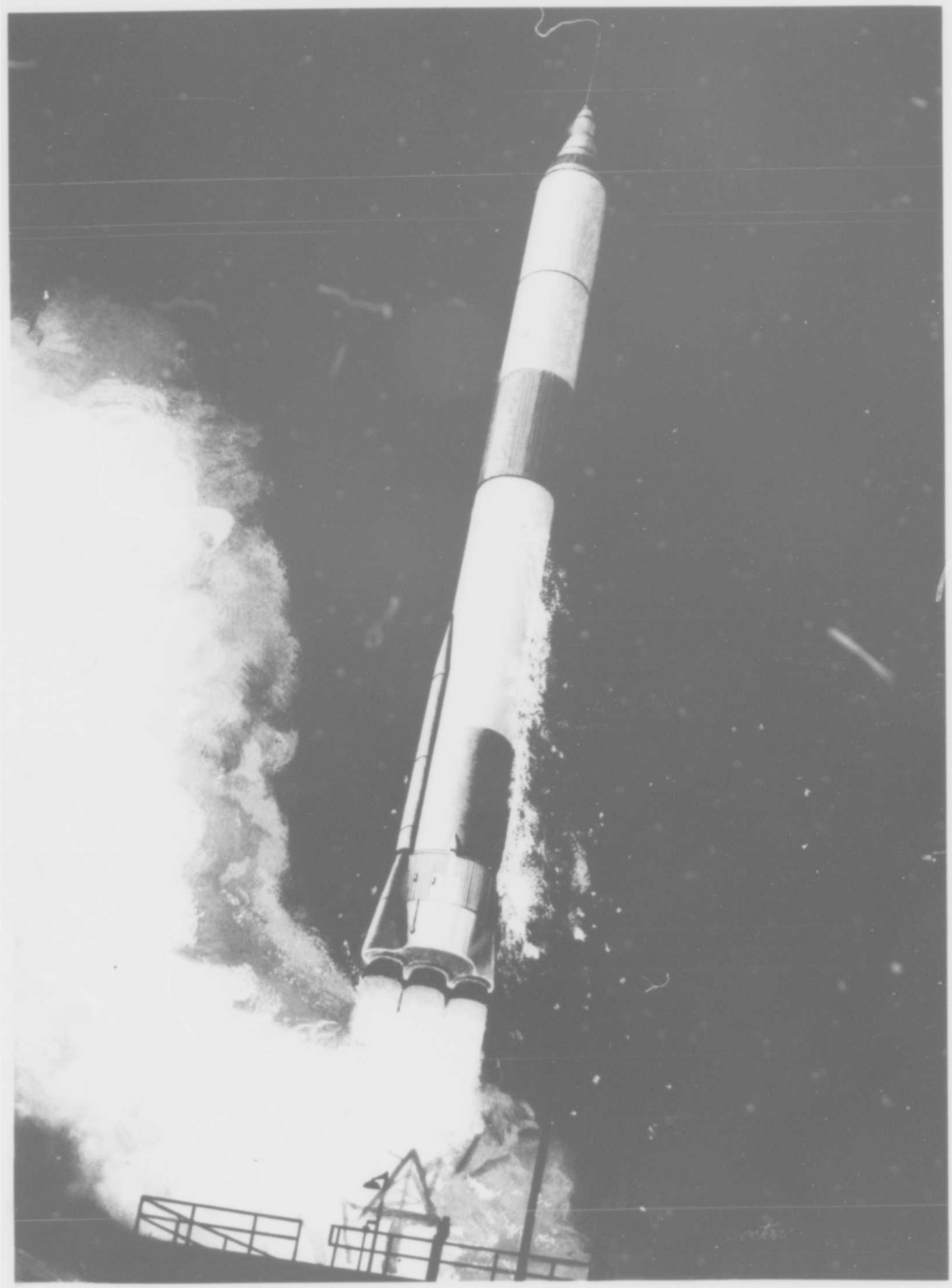
In addition to orbital research, Tassel can be used for simulating space flight conditions. For example, a manned lunar mission may be performed in the following manner: After the system is in orbit, torque forces are not applied. The system then simulates the free fall condition during the approximate 2-1/2 day trip to the moon. At the completion of the 2-1/2 days, torque forces are applied with sufficient thrust to obtain 1/6 g gravity environment, the same magnitude as encountered on the moon. This rotation can be maintained as long as the hypothetical lunar landing party is on the surface of the moon Rotation will then be stopped in order to simulate the free fall condition of the return trip.

The descent to earth would be made in the re-entry capsule

utilized in this system. Thus a complete manned lunar landing mission could be simulated without the vehicle leaving terrestrial space where extensive telemetry data could be accumulated on human reaction and with minimum danger.

Tassel is a stepping stone in the series of events leading to manned space flight and is a logical progression of accomplishments toward the space science program. Tassel would be followed by permanent space stations, such as the Outpost series proposed by K. A. Ehricke, having several men aboard with indefinite staytimes, then by lunar landing programs building up to interplanetary flight capabilities.

FIG. 1 ASCENT OF TASSEL USING ATLAS/CENTAUR



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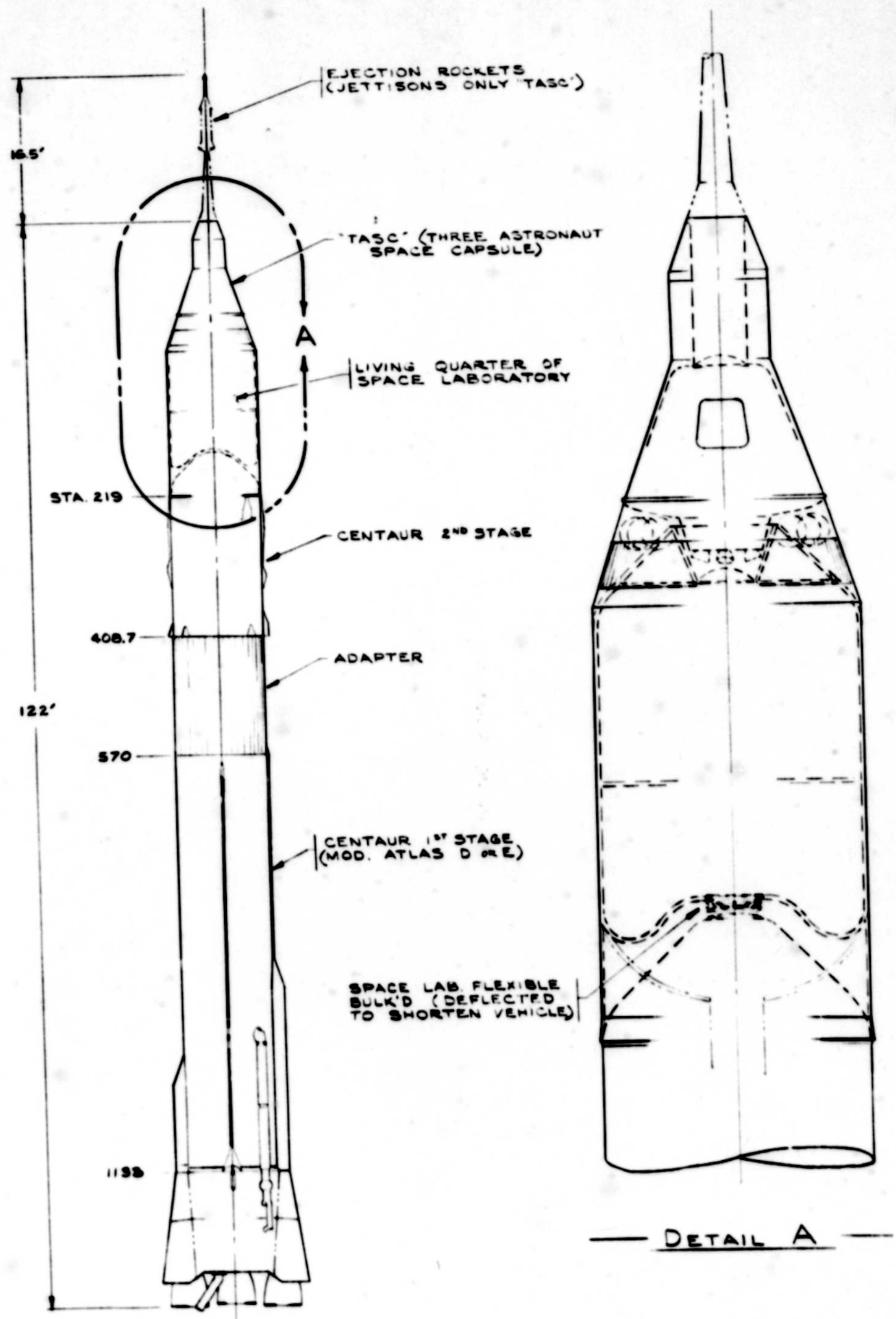


ASCENT CONFIGURATION

FIG [illegible] ASCENT OF SPACE LABORATORY "TASSEL"

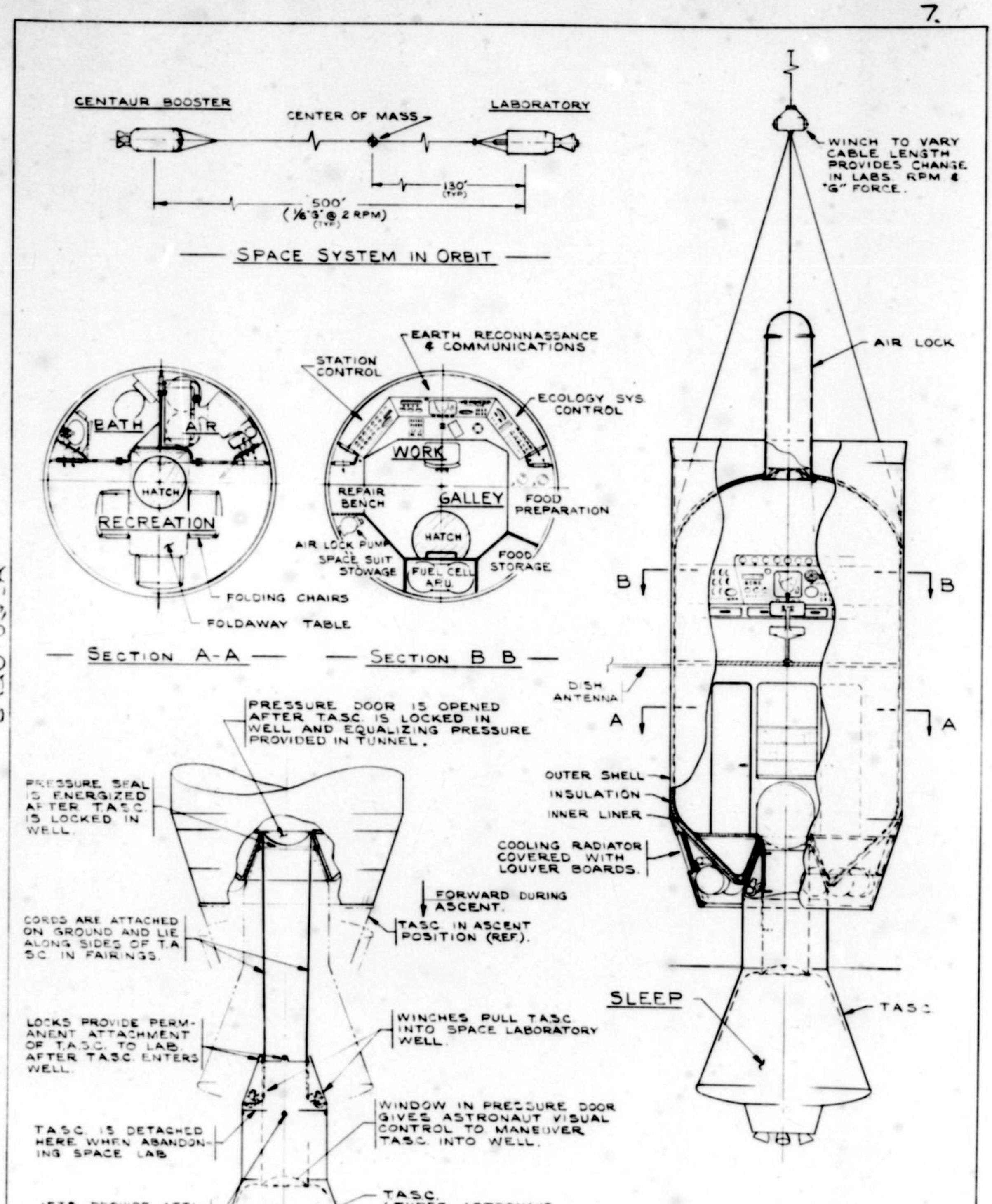


FIG. 3 "TASSEL"
THREE ASTRONAUT SPACE SYSTEM EXPERIMENTAL LABORATORY

TABLE I

Tassel Principal Data

Operational	1963
Booster System	Atlas/Centaur
Entry Vehicle	Tasc
Crew	3
Duration	1 to 3 weeks
Orbital Weight	~ $4\frac{1}{2}$ tons
Gravity Level	0 to 1g (1/6 g normal)
Orbital Altitude	200 n. mi.
Over-all Length	28 ft.
Over-all Diameter	10 ft.
Total Internal Volume	1,200 cu. ft.
Coriolis Acceleration (3 ft/sec. Rad. Motion / 2 rpm - 500' cable)	0.04 g
Circumferential Velocity (2 rpm - 500' cable	27 fps
Power Requirement (O_2 or H_2 Fuel Cell)	~ 500 Kwh

Exterior Radiating Surface Areas

Outer Shell Total (56% of area is adjacent to inner cabin capsule)	630 sq. ft.
Surface Area of Cabin Bulkheads	110 sq. ft.
Surface Area of Earth Return Vehicle	160 sq. ft.
Surface Area of Air Lock	40 sq. ft.
Surface Area of External Radiators (This area is part of outer shell and can be doubled if necessary)	50 sq. ft.

SUMMARY

This report presents a preliminary concept of a minimum-size space laboratory which could be operational in the early sixties.

The primary purpose of the laboratory is to serve as an experimental platform for establishing basic requirements and verifying basic hypotehses relating to the science of manned space flight. The primary missions of the space laboratory are:

a. To put men into space for extended periods and learn their physical reactions and to determine what they are capable of doing.

b. To determine whether artificial gravity must be provided to permit proper functioning of equipment and for the orientation and general well-being of the astronauts, i.e., to rotate or not.

c. To conduct laboratory experiments of a psychological and sociological nature in the confined environment of space.

d. To provide a platform for designing and testing apparatus and equipment for advanced space vehicles.

e. To conduct laboratory experiments of a biological nature by varying the atmospheric pressure, temperature and humidity during reduced or zero gravity conditions.

f. To select and condition crews for space station and early space expeditions.

g. To make real time observations and scientific measurements of earth and local space and possibly observations of deep space.

h. To provide a platform for developing and perfecting orbital rendezvous and space rescue techniques.

Early laboratory missions are planned as inclined orbits about the equator. Some later orbits could possibly be polar. (Radiation becomes an important factor if the orbit is above 30° latitude.)

The following items list the merits of the temporary space laboratory, Tassel, for early space research, phasing it between the Mercury program and the permanent space station.

a. Tassel would allow early space laboratory development because it is based on existing hardware, hardware under development, and hardware which can be obtained quickly with existing technology. The majority of the dollars spent, therefore, would go directly into hardware.

b. Instead of spending a large portion of development effort solving the orbital rendezvous technique to a workable degree before manned orbital research can begin, it appears more economical costwise and timewise to develop the two as separate programs rather than hold up one because of need for the other. Tassel has no need for rendezvous, but among other things can serve as a platform for its technical development.

c. Tassel does not require precise launchings into predetermined orbits or must it be located in an orbit to allow repeated

accessibility from a fixed launching site. The same launching site and communication network set up for the Mercury program could serve for Tassel, therefore no new equatorial launching sites or communication stations would have to be constructed. A far less expensive program thus would be provided at a much earlier date.

d. Not all missions can be satisfied with one permanent orbit. Tassel can make successive orbital flights at different altitudes and inclinations. If Tassel is programed for a particular orbit and fails, it is more than likely that whatever its orbit, provided it is not dangerous, will be suitable for use. This is in contrast to a rendezvous flight wherein a miss is a complete loss.

e. The cost of an expendable vehicle such as Tassel is perhaps a bit more expensive than a permanent space station when considered over a long period of operation provided very few rendezvous misses are encountered and the launching sites are not included in the cost. Misses are a hard item to appraise but could well mean that Tassel experiments are far less expensive in over-all operation.

f. One of the important purposes of the space laboratory is to serve as a platform to develop and optimize equipment for advanced space vehicles. Subsequent firings of Tassel could carry into orbit new advanced designs to be evaluated. These could be

incorporated at the factory rather than to attempt salvage of reworked equipment as would be necessary aboard a permanent space station. Rework of equipment aboard a permanent station would appear to be very restricted, time consuming, expensive and often dangerous.

g. Tassel can be orbited at relatively low altitudes because the residual drag during its limited lifetime will not appreciably decay the orbit. The lower altitudes allow a greater payload and a lighter-weight re-entry vehicle. In case of a strong solar flare where it is mandatory to abandon ship, the lower altitude permits the astronauts to return home more quickly than they could from higher orbits.

h. Because Tassel is expendable, no heavy shielding against solar flares is necessary. The earth-return capsule is part of the cabin and is in a very convenient position for quick bailout if radiation becomes excessive. Thus the astronauts can jump into the capsule and depart in a quicker time than the astronauts of a permanent space station can don their space suits and work their way out of the airlock to their lifeboats.

i. It may be necessary on return to earth before leaving a space vehicle to provide a G-level of one or more to condition the astronauts for their re-entry trip. Tassel, with its ability to change its G-level by merely shortening the connecting cable, is very adaptable to such a requirement.

j. Because Tassel creates its artificial gravity by rotating two masses connected by cable, it is possible to reduce the rotational period and coriolis side effect to a low level and still maintain suitable centrifugal acceleration by designing a long cable into the system. The resulting low period reduces the problem of the rotating communication antenna and that of general orientation.

k. Since Tassel is a temporary space system, it is free from the expense of long-term orbital maintenance such as would be required of a permanent station. Once a permanent system is operational, it must be maintained whether high periority research is being conducted or not. This could result in a rather expensive overall cost.

The short-term system, Tassel, would be launched and operated only when required by concentrated programs. This makes it possible to evolve a system step by step with redesign periods between each successive flight, thus, building up to an ideal space system. Other experiments perticularly in the biomedical fields may require several Tassel laboratories in space at one time or there may be waiting periods for reconstruction when none will be in operation. Tassel launchings would therefore by nature be very flexible.

1. Tassel flights could easily be postponed if bad weather persisted. To keep the permanent system operating these postponements would be somewhat limited because personnel and supplies would have to get through to keep the station in continuous operation. Therefore, a higher structural factor would have to be designed into the structure of the permanent stations support vehicles than into the structure of Tassel.

The system consists of an Atlas/Centaur missile with a payload containing a "Mercury-type" capsule and orbital living quarters. The unique characteristic of this space laboratory is that it would be fired into orbit as a unit, i.e., the astronauts, their living quarters, their supplies and return vehicle would be launched at the same time. This eliminates the complex problems and expense of rendezvous in space.

The space laboratory would house three astronauts with sufficient provisions for several weeks staytime with accommodations for work, eat, sleep, toilet and exercise. These activities, generally, would be performed under artificial gravity created by rotating a cable-connected two-body system about its common center of mass. The gravity level may be varied by changing the laboratory's rotational velocity. This may be accomplished by increasing or decreasing the cable length since the law of conservation of momentum applies. Calculations show that by adding a winch to the cable system the versatility feature of changing gravity levels may be obtained at a relatively small cost to the overall weight. This being compared to changes in angular velocity

of a fixed cable system with rocket impulse.

A long connecting cable joining the two-body system provides suitable gravity levels at low rpm. The accompaning side (coriolis) accelerations are also quite low. For example, a 500 foot cable system rotating at 2 rpm provides about 1/6 G vertical acceleration. At 3 ft/sec. radial velocity, the resulting side acceleration is about 20% the vertical. On the other hand, a shorter system with a 27 foot long cable at 2 rpm the side acceleration is about 4 times the vertical.

The concept of the space laboratory is so arranged that most orbital experiments and operations may be carried on by a shirt sleeved crew. In case of emergencies such as meteorite penetration, solar flares or other, crew members can escape to their re-entry capsule without having to don space suits and pass through air locks. This allows rapid departure which is an important safety precaution for crew survival.

Generally speaking, the space laboratory operates in an orbit free from any appreciable radiation except strong solar flares. At times of high solar activity, no space laboratory will be orbited. If a flare should be emmitted from the sun or excessive radiation from other sources be encountered during flight, the astronauts will have sufficient warning from their own radiation counters and from the earth observations to bail-out and return to earth before radiation damage becomes serious. (It is believed that a little over a half-hour period would be permitted after a large flare emits before a dangerous accumulated radiation level is reached.)

Although the system concept of Tassel is based on the maximum payload "two-start" trajectory, i.e., utilizing an interrupted thrust transfer ellipse, it may be more desirable from the viewpoint of existing guidance and tracking to place the laboratory immediately into orbit ("one-start" trajectory). This latter trajectory would reduce the payload approximately 2,000 pounds which would result in decreasing the crew size, staytime or experimental capabilities. Growth Centaurs would allow more favorable trade-offs.

Three astronauts is believed a minimum crew for carrying out full duration operations. For first flights with short orbital life it may be desirable to operate a two-man system. However, it appears most economical to design for three and eliminate one from the flight if the requirement due to safety, payload limitation or other reasons deem it necessary.

The activities and tasks assigned to the first manned flights of Tassel will probably be restricted to the normal operations of establishing the laboratory in orbit. This will consist of phases starting from launch to orbital injection, then orienting the earth-return capsule for cabin access, detaching the Centaur booster tank and unreeling it to cable's length, initiating rotation for artificial gravity, entering the space cabin and putting the station into operation. After a short stay in orbit the astronauts may return to their re-entry capsule and leave for earth.

Much would be learned from the first successful flight of Tassel, both from the standpoint of vehicle operation and from the standpoint of the astronauts' ability to perform in space. Conditions will be as favorable as possible to achieve a successful mission. Succeeding flights would then begin the planned experiments.

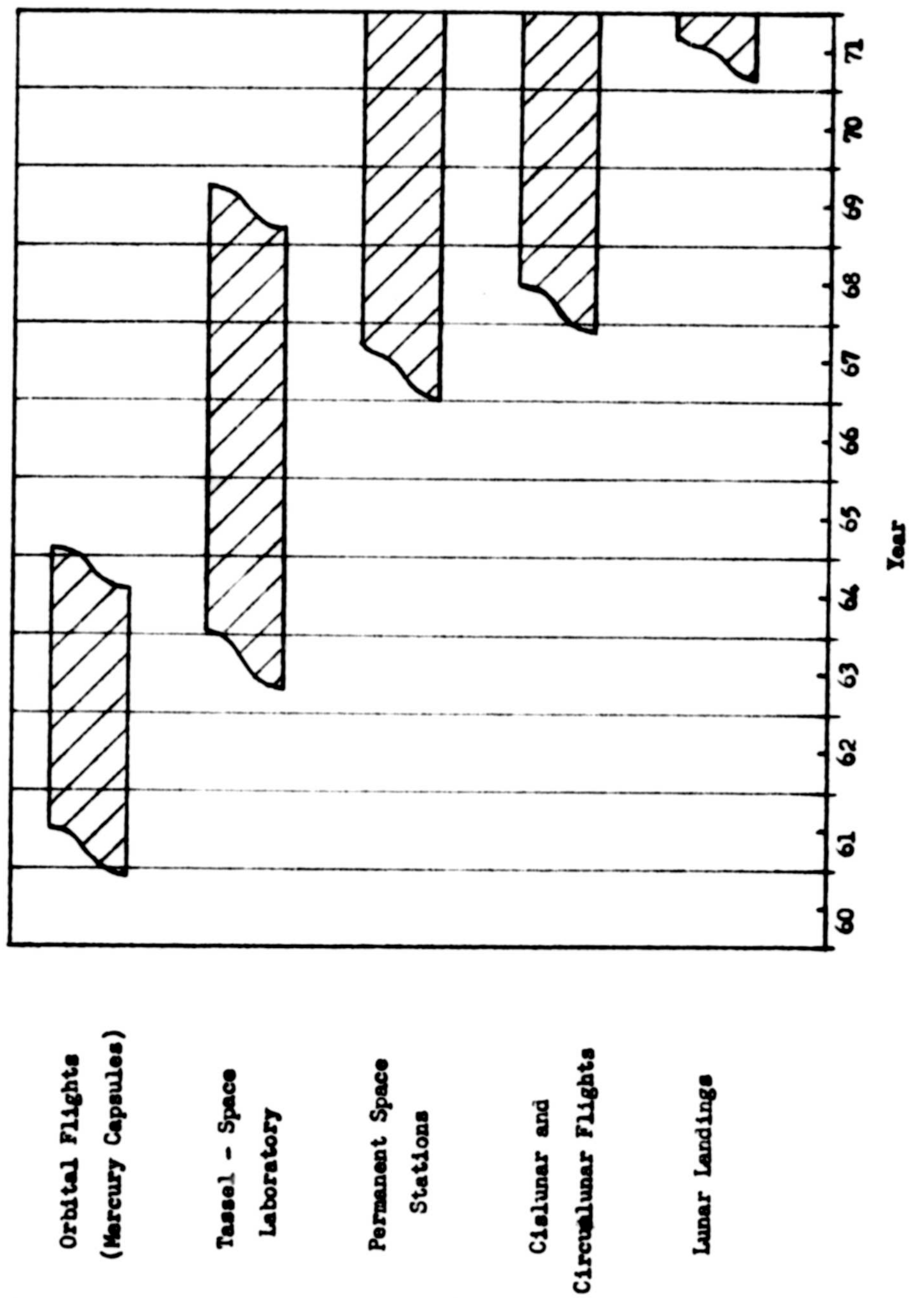
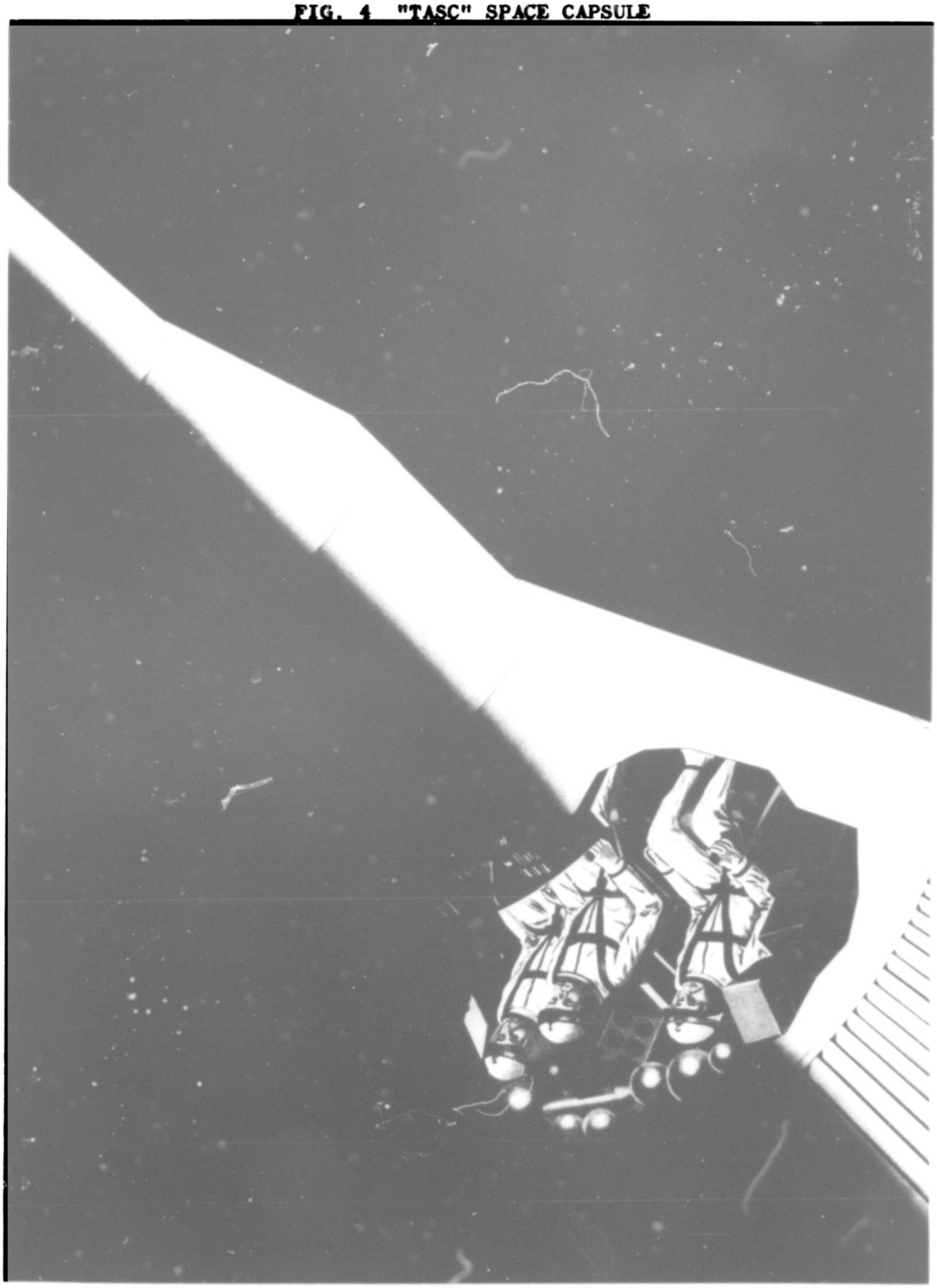


Table 2 — Estimated Time Phasing of Manned Space Systems

FIG. 4 "TASC" SPACE CAPSULE



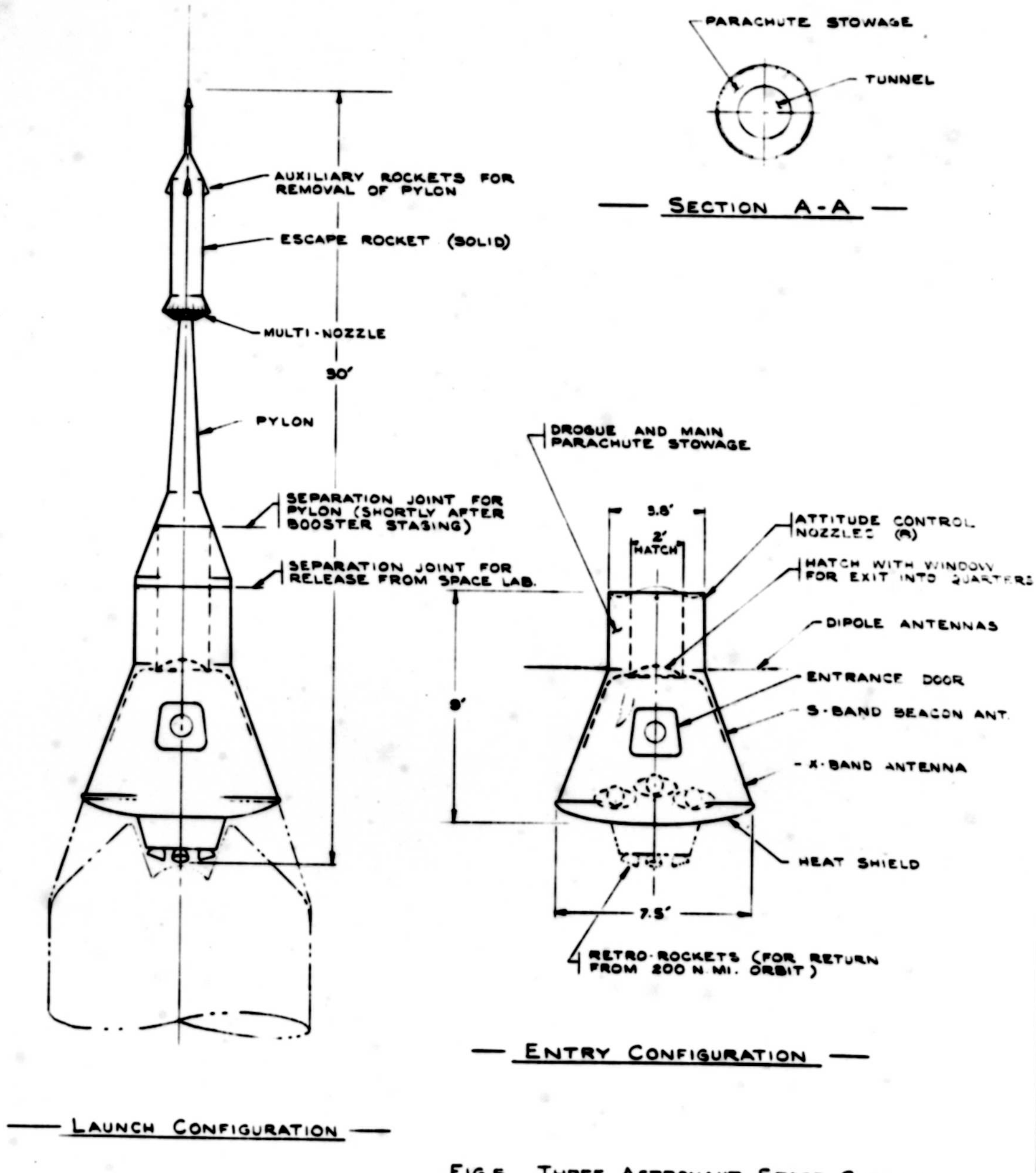
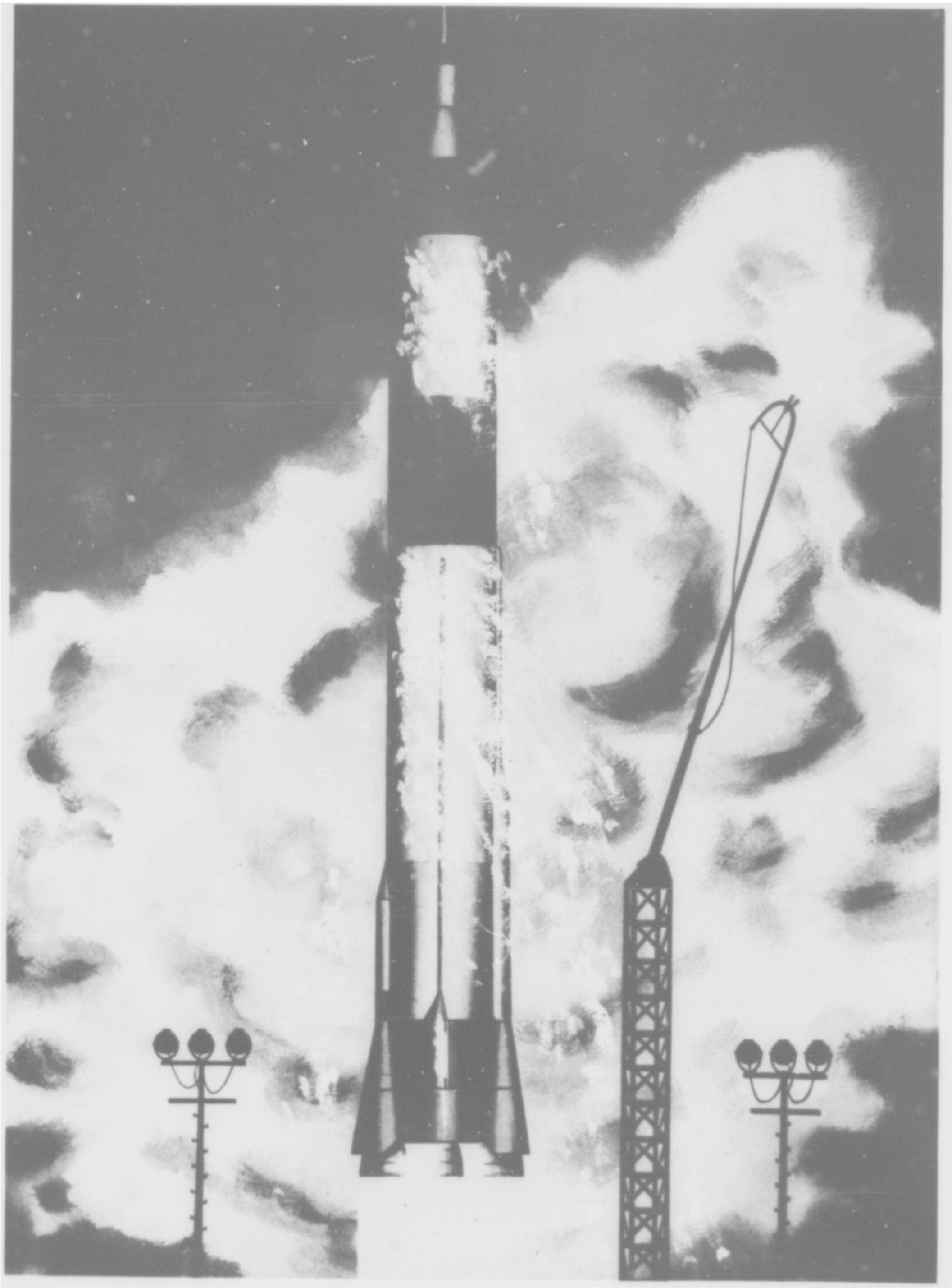


FIG 5 THREE ASTRONAUT SPACE CAPSULE

FIG. 6 "TASC" LAUNCHED BY ATLAS/CENTAUR
FOR TEST & ORBITAL RENDEZVOUS EXPERIMENTS



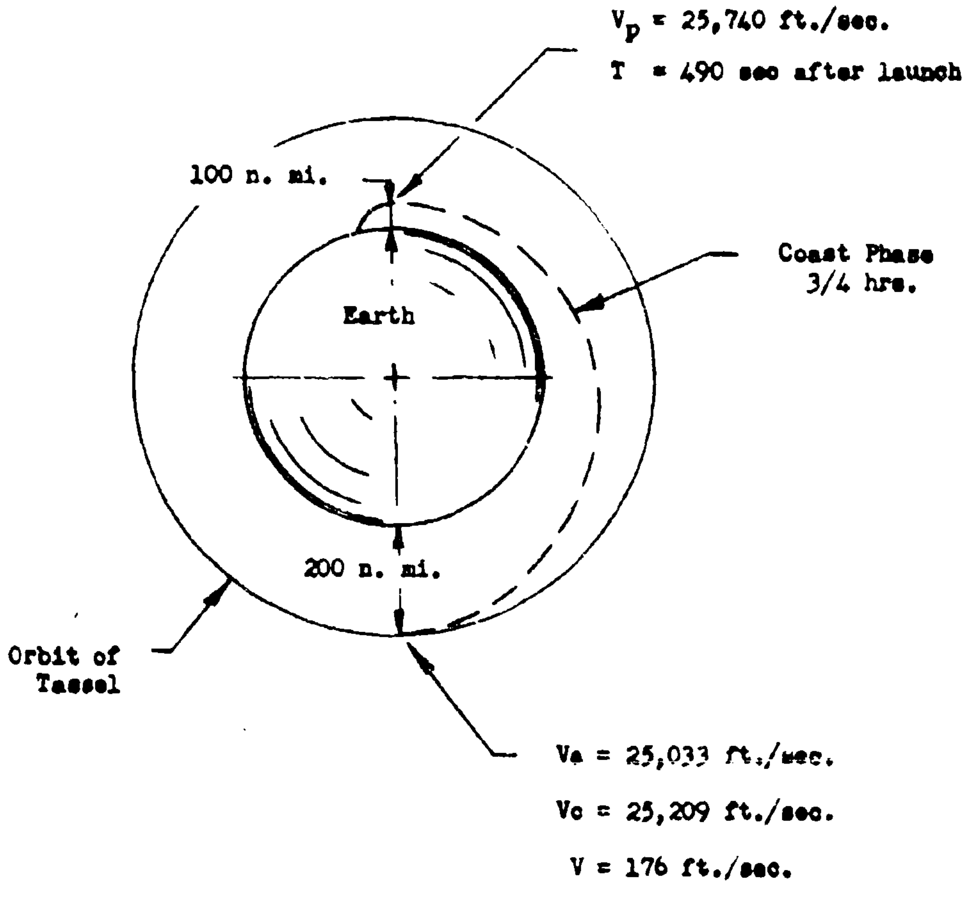


Figure 7 Trajectory of Tassel

DISCUSSION

The first frontispiece portrays Tassel in a 200 n. mi. orbit The laboratory with its re-entry capsule is shown in the foreground. The body on the opposite end of the cable is the depleted Centaur tankage. After Atlas burnout, the Centaur provides impulse for injecting the Tassel into orbit. The two bodies are rotating about their common center of mass, which is along the cable about a quarter of the distance to the Centaur. This rotation creates centrifugal gravity for the astronauts comfort.

The second frontispiece is a cutaway of the space laboratory showing the three astronauts and their cabin arrangement.

The space cabin consists of two floors. The upper floor is the work center and laboratory area, and it also contains the galley. The lower floor is the recreation room with sanitary facilities in an adjoining room and life support equipment in another adjoining room. Below the lower floor in a convenient location for jettisoning is the re-entry vehicle Tasc (Three Astronaut Space Capsule). Tasc is a sleeping facility during orbital stay, and it is kept in readiness for earth return in case of emergency.

The design of Tassel is influenced by its relationship to the Atlas-Centaur booster system, i.e., about 4½ tons, 10 ft. in diameter and relatively short in length. The complete launch

vehicle is shown in the artist's conception in Figure 1 and as a line drawing in Figure 2. The modified Atlas with a Centaur upper stage carries Tassel as its payload. The forward end of the Atlas oxidizer tank is cylindrical instead of conical as in the ICBM. Atlas/Centaur flight tank pressures are maintained at their normal values; the tanks are pressure-stabilized so that the skin material remains in tension for all expected loads of ascent.

The overall height of the ascent vehicle is about 122 feet with a 16.5 foot capsule escape pylon added, thus, giving a total of about 138.5 feet. The elliptical bulkhead of the cabin is made flexible and is partially deflected to shorten the adapter length between the cabin and the Centaur tank and to save on the overall length of the vehicle. The shorter missile allows a more favorable condition when considering aerolastic bending moments which are created during ascent.

For emergency, the re-entry capsule Tasc, housing the astronauts, is placed on top of the launch vehicle. This sets the capsule in a position that allows split-second jettisoning in case a malfunctioning of the ascent vehicle should occur. Directly below Tasc is the space cabin. It is pressurized, but uninhabited during launch. Its internal pressure is only enough to sustain structural loads during ascent and as the vehicle ascends, the internal air is reduced. This will maintain a constant pressure

differential protecting the cabin walls from having to be designed to accommodate excessive loads.

The ascent configuration with Tasc on top, the space cabin in between and the boosters below provides a functional profile and places the units in their proper order for orbital operations.

Since the Centaur arrives in orbit as an expended booster, it is utilized by the space laboratory as a counter mass for creating centrifugal acceleration. This is done by removing the Centaur from the laboratory to cable's length by an impulse obtained either from springs or small jets. When the cable system is rotated, the resulting acceleration acts outward from the common center of mass. Therefore, the cabin's top is so positioned that it faces in the direction of the Centaur tank. Thus, during ascent, the cabin's top would be facing the Centaur below, i.e., the cabin would be upside down with respect to the missile. This, however, is an advantage since it allows all equipment underpinning to be designed as light weight tension ties during high ascent G loads and then serve as normal below table level compression members during low G orbital operations.

During ascent the capsule Tasc provides protection for the astronauts. They lie in a supine position resisting acceleration loads thru their backs. The capsule being similar in design to the Mercury capsule is right side up with respect to the ascending missile, but, upside down with respect to the space cabin and the

artifici_al gravity which will be produced by rotation while in orbit. In order to make use of the capsule as sleeping quarters and provide easy access for emergency departure and eliminate the need for strapping personnel to the ceiling, the capsule must be inverted after arrival in orbit.

This is not considered a difficult maneuver for the first astronaut in the Mercury capsule will be required to perform a similar task in order to re-enter his capsule into the atmosphere. Upon orbital arrival Tasc will be oriented with respect to the cabin and can be turned over and rejoined in the following manner: When Tasc is released from the cabin in its gravity-free environment, it is moved slowly away by compression springs. Two low-streng'' cables attaching the two bodies together have enough slack to allow a few feet departure. With control jets, autopilot and manual-visual control aboard the capsule, it is a simple matter to flip Tasc over. Then by means of two small winches, the capsule is pulled into the tapered female seat provided on the cabin. The capsule is then locked in place and pressure seals energised. (The joint may be later caulked by hand if leakage thru the seal becomes excessive.)

With the re-entry vehicle Tasc located, the tunnel between it and the cabin is ready for pressurisation. This then may be followed opening the top door of Tasc and the low r or of the

cabin and thus gaining entry into the laboratory.

With this maneuver completed, the Centaur on the opposite end of the cabin is released and slowly departed to cables length. A shock absorber is mounted on the cable to absorb the shock load when this cable becomes taut. The shock absorber programs the rotation rockets on the vehicle which starts the system rotating. A G-level of any desired magnitude can be obtained through variations in angular velocity. For example, an acceleration of 1/6 G may be obtained in the laboratory.by rotating the system with a 500 foot connecting cable at about 2 rpm. The gravitational environment may be easily adjusted to any desired level simply by adjusting the cable length varying the rotational velocity of the system. During this maneuver, the astronauts will probably be inside Tarc. After initiating rotation, the cabin can be entered and the space laboratory put into operation.

Why Three Astronauts?

To answer the question, there are of course several factors that must be considered. First, during the period of the proposed space laboratory, there will be only one reliable booster system available to accomplish the task, namely, the Atlas-Centaur. This booster system has a fixed weight payload capacity for low altitude orbits of about 4½ tons. Figure 8 shows that 4½ tons (9000 lbs) would allow a space laboratory to orbit 4 men for a few days, 3 for about 3 weeks or 2 for nearly five weeks. Therefore the

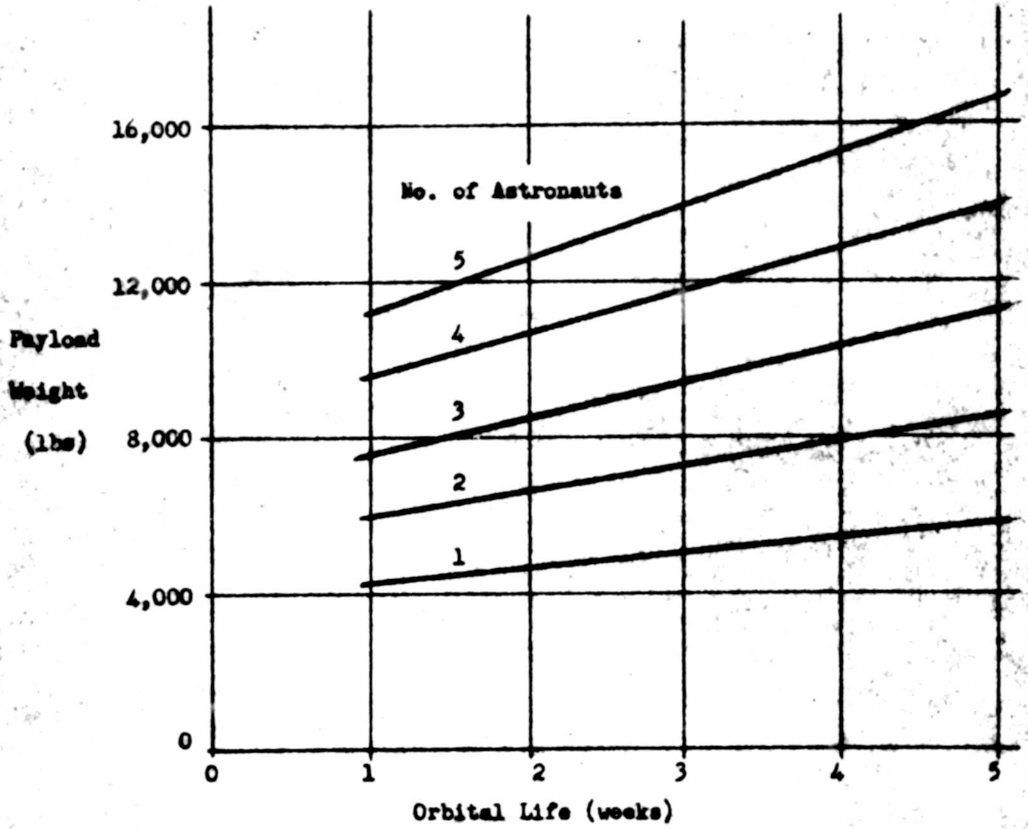


Figure 8 Lifetime vs Payload for Various No. of Astronauts

space laboratory is limited to a maximum of four. The second factor is the minimum number of crew members required to perform intended missions which include manning the vehicle and performing experiments.

The minimum number of crew members to man a space laboratory appears somewhat arbitrary. However, if certain safeguards are observed along with normal operations, it points to a conclusion that someone must be on duty at all times. Although every effort will be made by designers to develop a cabin system capable of automatically controlling its pre-set terrestrial environment thereby permitting the astronauts to sleep or concentrate on the experiments required to accomplish the mission, it appears far too risky in this new science to expect 100% reliability of the systems. Other tasks requiring continuous duty would be radio communication, surveillance of other crew members and emergency duty such as quick fix for punctures or breaks in the cabin capsule, immediate repair in event of electric power failure or other such operating equipment. It is true that television and telemeter communication with ground facilities might replace a man on duty and alert the crew if emergencies prevail, but, this would require a very costly network of ground stations which are not available or expected to be available during the period of the space laboratory. Since someone must be on duty at all times, it seems in keeping with man's standard practice to be on duty 1/3 of the day allowing him 2/3 of the remaining for sleep, recreation and performing laboratory

tasks. (Laboratory tasks would consist of experimental ventures outside the cabin, changing the gravity level in the cabin and determining its effect on the crew and equipment, experimenting with animals, optimising future spacecraft hardware, etc.) Operator's duties plus experimental tasks appear to be a full program and would keep an astronaut quite busy. With this arrangement, 3 astronauts would be a minimum crew.

There is another aspect to the laboratory's mission which is an important parameter in determining man's requirements for future spacecraft designs and missions; it is that of establishing a man's psychological and sociological adjustment to others in the isolated closed system of the space cabin. A three-man system would allow an astronaut working contact with at least one of the other two crew members through most of his working periods. This is essential and is possible only with three or more crew members.

Although certain sociological peculiarities exist in groups of threes, such as two joining forces against the third, it appears that this condition is not particularly valid on a daily schedule since usually only two will be associating at any one time. The third will be off-duty reading or sleeping in his isolated compartment.

One of the space laboratory's main functions will be to determine man's endurance under extreme conditions of pressure, temperature and atmospheric content at reduced gravity. It is very possible that one member will become quite ill when his limit is reached

and be slow in recovery. Under such conditions, even a three-man crew will be overburdened with extra work.

It seems quite clear that a minimum of three would be required for trips to the moon. The space laboratory would be more useful if it were able to train crews and develop equipment for such a mission.

From the foregoing discussion, it is apparent that a crew of three or more is necessary to man the vehicle. Four would cut the orbital staytime down to too short a duration.

The Crew

In picking crew members, it would be rather unlikely that fewer than three astronauts could be found who were proficient enough to physically and intelligently meet the requirements of a space laboratory.

Since the space laboratory has many functions, the astronauts not only will have to be adaptable to space flight, but must also be specialists in particular fields to maintain the vehicle and to accomplish a successful mission. It would be practically impossible to expect to find an astronaut candidate who was a "jack-of-all-trades." He, of course, could perform limited duties in many fields, but more than likely would not be very proficient during cases of emergency. Three types of experts appear to be required:

two engineers and a medical doctor. One engineer would be an electronics expert. He would have a complete understanding of the communications, telemetor and electronic systems. He would be proficient in theories of trajectories, guidance, navigation, errors, recovery, etc. The second engineer would be an expert in operating and maintaining equipment aboard. He would serve as an inspector, a trouble shooter, a mechanic and a designer. Since simulating reduced gravity conditions on earth is virtually impossible for extended periods, some minor re-designs or alternate systems may be necessary on operating equipment or test equipment. The third astronaut would be a medical doctor since most of the experiments performed in the space laboratory will deal with man's ability to perform in space. He will keep tab on the crew's physical condition as well as to determine his limits during the various experiments.

Although each man has a specialty, he must have a fairly workable understanding of the others duties. He must serve his shift as station operator and must be able to prepare food and keep the laboratory shipshape as well as having a well grounded schooling in anticipated emergencies.

Artificial Gravity

Many problems of manned space flight would be eliminated if artificial gravity (or centrifugal acceleration) were eliminated. On the other hand, new problems are created. Perhaps the most fundamental questions to be resolved by Tassel is the answer to

this problem. A few notes on the subject are discussed below.

If gravity is created, the design of equipment aboard the vehicle is simplified because it can be built by long-adopted engineering practices where gas convection and liquid flow are natural. Testing of such equipment can be done on earth and reduction in gravity accounted for by appropriate formulae. Man also benefits in that he maintains his equilibrium — he has an up and down to orient himself. When he exhales, the warm gases rise due to weight differences between warm and cool air and therefore he does not rebreathe stale air. Also his body heat does not have to be blown away with fans. However, rotating a vehicle creates problems in communication, vehicle orientation, observations, etc.

Only short-term experiments with true weightlessness have been performed. They resulted in varying degrees of reactions on personnel such as a pleasant feeling for some, while others suffered from disorientation and motion sickness. Only crudely simulated long-term weightless experiments have been performed, these mainly in water. It is worthwhile to note a long-term test simulating weightlessness conducted and performed by Dr. Graveline at San Antonio. He immersed himself in water for a week with only his head protruding. He was allowed all the rest he needed and spent his hours operating small levers underwater when work problems were flashed on an electronic panel. Frequent metabolic checks showed adequate balance

of food intake and energy output. It was reported that during the week he only slept 7 hours. The organs of his body functioned normally, his bones and muscles responded quickly to weightlessness but daily examinations showed his muscles were getting softer. Calcium and phosphorus left the bones and made him feel loose jointed. Dr. Graveline would leave the water for short periods during the day but he said, "During the last few days of the experiment, it was actually a relief to get back into the water."

Immediately after Dr. Graveline's underwater experiment he was put into a centrifuge where he blacked-out at a little under 5 g's.

Experiments of this kind very pointedly show that problems of weightlessness and reduced gravity must be solved before any attempt at manned space flight.

TASSEL - SPACE LABORATORY WEIGHTS

(Three Astronauts - 3 Weeks)

Crew and personal equipment	750 lbs
Re-entry capsule (Tasc - Unmanned - orbit)	3400
Space Cabin (outer sheel pressurized, inner capsule, insulation & furnishings)	2000
Ecological system	1800
Electronics and Comm. (incl. antenna & telem)	300
Attitude control system	200
Power supply (Batteries, fuel cell & equip.)	600
Rotation rockets, cable winch adapters, etc.	300
Instrumentation	50
Total useful load	9400 lbs
Centaur stage	3600
Total orbital weight*	13000 lbs

* Based on orbital altitude of 200 n. mi. (satellite lifetime ~ 50 days.

TASSEL ECOLOGICAL SYSTEM WEIGHTS

(Three astronauts - 3 Weeks)

Oxygen and Storage equipment	420 lbs
Food	200
CO_2 absorber system	375
Water absorber or precipitator	350
Odor absorber	80
O_2 – N_2 cabin leakage	75
Water and distiller*	100
Ecological system equipment	200
Total	1800 lbs

* Note: most water available will be from bi-product of fuel cell.

Weights and items in above table are tentative.

SYSTEM DESCRIPTIONS

Nature of Tassel Orbit

The orbit of Tassel can be quite flexible within prescribed limits. These limits depend upon the characteristics of the vehicle, the environment in which the vehicle must operate and the launching facilities to be available. Since rendezvous is not a requisite in establishing Tassel, there is no need for extremely accurate orbits or for orbits that must pass over certain launch sites at regular intervals. (An equatorial orbit is desirable for a rendezvous operation because the vehicle passes over an equatorial launch site approximately every 1½ hours. Earth rotation and orbit regression creates problems for other than equatorial orbits.)

Radiation is a limitation. The Van Allen belt, although yet uncertain, is considered a ring structure, approximately symmetrical about the geomagnetic axis, restricts the vehicles altitude to roughly 350 n. mi., no matter what its orbital inclination should be. However, restricting the vehicle to equatorial orbits of 30° to 40° maximum latitude appears to provide the most sheltered region. If the orbit be polar, then radiation from solar flares becomes a hazard.

Orbital lifetime limited by the density and shape of the vehicle and the density of the atmosphere, determines the lower limit of the orbit. Figure 9b shows orbital lifetime as a function of

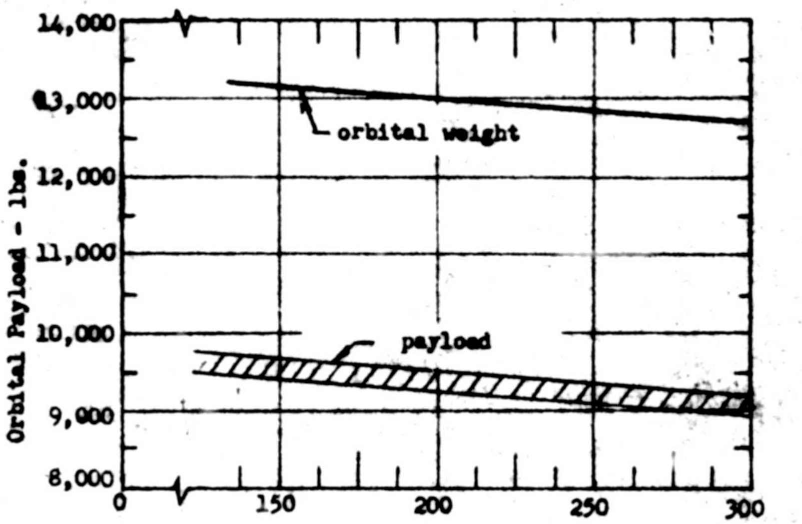


Figure 9a Atlas/Centaur Orbital Payload
Data from Jon Andruyko - Aerophysics (2/60)

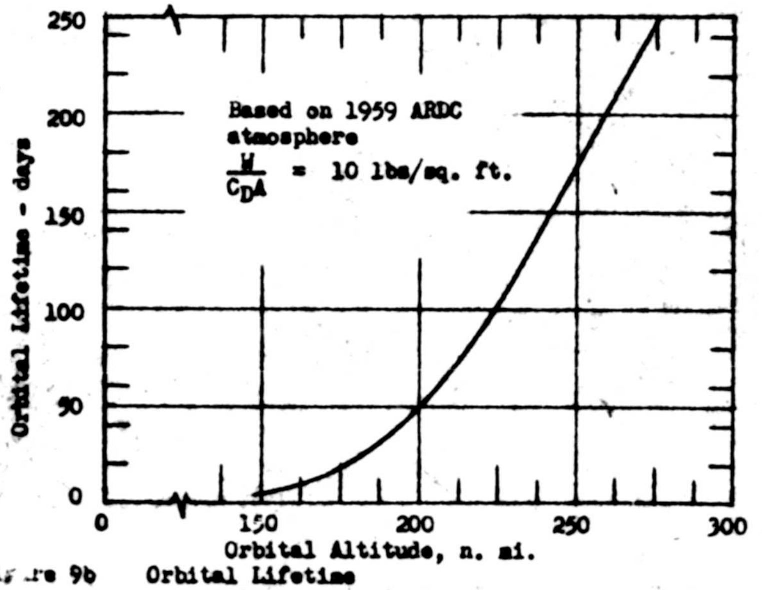


Figure 9b Orbital Lifetime
Data from R. C. Frayer, Predesign (8/59)

altitude based on 1959 ARDC atmosphere and a $\frac{W}{C_d A}$ of 10 lbs/sq. ft.

Since Tassel is designed to operate for a duration of 21 days, the curve shows that a minimum altitude of 180 n. mi. will be required. However, due to guidance tolerances and other uncertainties, a 200 n. mi. orbit would be reasonable. From the curve the orbital staytime of the 200 n. mi. orbit would be 50 days or about 2½ times the required life of the space laboratory. This margin is true only if the vehicle's orbit is close to circular. If error due to guidance, propulsion or other equipment should take place, an elliptical orbit may result and the total staytime would depend upon the shape of the orbit and the altitude of its perigee. Except in extreme cases the vehicle orbit would be satisfactory.

Orbital Data

200 n. mi. circular

92 min period

$\frac{24 \times 60}{92}$ = 15.65 revs/day around earth

For each pass over the equator, the earth rotates $\frac{360}{15.65} = 23^{o}$

Velocity of vehicle 25,280 ft/sec.

Orbit Precession

With a 200 n. mi. circular orbit inclined 30° with the equator, the precession rate, Δm, would be approximately as follows:

$$^{*}\Delta n \approx \frac{10.00}{(1-\epsilon^2)^2}\left(\frac{R}{a}\right)^{3.5} \cos i \qquad \text{deg/day}$$

where:

ϵ = eccentricity of orbit

R = earth radius, n. mi.

a = semi-major axis

i = orbital inclination

$$\Delta n \approx \frac{10.00}{(1-0^2)^2}\left(\frac{3440}{3640}\right)^{3.5} \cos 30^\circ$$

$$\approx 10.00 \times 0.82 \times 0.866$$

$$\approx 7.1 \text{ deg/day}$$

Thus, the period of precession is about

$$P = \frac{365}{7.1} = 51\tfrac{1}{2} \text{ days}$$

If Tassel is tumbled in the plane of its orbit immediately after arriving in orbit, the vehicle would precess thru an angle of 7.1°/day x 21 days = 149° at the end of a 3 week stay period.

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* See "Oblateness Perturbation of Elliptical Satellite Orbits", - L. Blitzer and A. Wheelan, J.A.P. Vol. 28, page 279, Feb. 1957.

Space Laboratory

The laboratory consists of three major bodies, the space cabin, the earth return vehicle "Tasc" and the depleted Centaur system. Tho three units arrive in orbit joined together. Before the laboratory can be established, Tasc must be inverted, the Centaur tankage must be removed to cable's length and the entire dumbbell shaped system put into rotation. At present the depleted Centaur system is considered only as a counter mass for the other two bodies for creating artificial gravity. However, as the space program advances, the Centaur may provide, in addition to the above, a remote platform for conducting radiation experiments, communication experiments or may serve as a housing for the laboratory's future nuclear electric power supply. (A fuel cell located inside the cabin is the contemplated power supply for the first space laboratory models.)

The space cabin and earth return vehicle, "Tasc", comprise the center of activity for the astronauts. Although Tasc is a separate body, it is joined to the cabin and a tunnel is provided for free passage between the two vehicles. Tasc serves as a sleeping room for the laboratory during orbital stay. This is desirable primarily from the safety standpoint, since rapid emergency departure from the laboratory would require that the resting astronaut be out of the way of others and in escape position, thus, preventing loss of valuable time during bail-out. Tasc's ready access to the cabin, its remoteness from others and its quietness provides a therapeutic retreat for the

astronaut after a day of anxiety and strain. The constant, inescapable presence of fellow humans is considered to be a stressful situation. Arctic explorers and others have described the disruption of crews whose members came to hate the sound and sight of their companions. By treating Tasc as a separate room, it will provide this necessary escape as well as utilizing its volume effectively.

Tasc is located farthest from the center of rotation so that its release from the laboratory does not involve cable fouling or impact by rotating structure. The fact that it is farthest from the center of rotation means that its gravity level is the highest of the inhabitable areas, thus allowing maximum comfort for the resting astronaut. Tasc is much heavier in construction and smaller in surface area making it less penetrable than the cabin, therefore, it provides the astronauts with an escape shelter to sit-out the hazards of a potential meteorite storm. Tasc is air conditioned during orbital stay by the cabin system, but the capsule could quickly switch over to its own system if needed. An air lock between the two bodies allows passage even though there exists a pressure differential between the two.

The space cabin would be the life support system and laboratory for the astronauts. It must be designed as a highly reliable, hermetically sealed compartment with fail safe devices for detecting leaks. A minimum amount of human effort would be required for its operation and maintenance.

The cabin includes living facilities for eating, recreation, washing and sanitation. Various stimuli such as radio, TV, games, etc., would be available. The interior is planned to be comfortable, well lighted and attractive. The work spaces, controls, instrument panels, etc., will be human engineered insuring maximum efficiency of the astronauts.

At each end of the cylindrical cabin is an entrance. One end, the lower, is the hatchway permitting passage to and from the re-entry capsule, Tasc. The upper entrance is an air lock permitting the astronauts wearing their space suits to leave the space cabin and perform special missions outside.

It appears that most of the early missions performed by Tassel will pertain to tests conducted inside the cabin subjecting the astronauts and equipment to various space flight conditions at reduced gravity. Later research in rendezvous, rescue, orbital assembly, etc., will require modification to the basic vehicle depending upon the requirements at the time.

The basic cabin layout is shown in Figure 3. Its structure must be light-weight and capable of withstanding accelerations, vibrations, aerodynamic heating, temperature variations and pressure differentials encountered during ascent and during orbital stay. The cabin will have to be hermetically sealed to prevent any appreciable loss of atmosphere.

The walls of Tassel are made up of three sections; the outer shell, the thermal insulation and the inner pressure liner. The outer shell withstands imposed structural loads and acts as a bumper against meteoric penetration. The thermal insulation protects the inner liner which is an integral part of the sealed laboratory.

The cabin consists of two floors functionally designed and having several centers of activity. The lower floor contains three compartments separated by structural partitions. They are, the bathroom, the life support equipment room and the recreation room.

The upper floor is primarily a work center. Experimentation, observation and the monitoring of various systems is done here. A control console, work bench, galley, storage, space suit closet and the laboratory's electrical power plant are located on the upper floor. Cryogenic fluids for operating the power plant and replenishing the air supply are planned to be stored in insulated containers inside the vehicle. However, it may be found advantageous to place them outside in shaded vacuum depending upon weight and permissible boil-off rates.

A 500 Kw-hr. H_2O_2 fuel cell is planned for the laboratory's power supply. 250 watts would be available for electronic equipment and 750 watts for life support and miscellaneous controls, thus, the fuel cell would produce a continuous 1000 watt output for 3 weeks. The fuel cell is located near the control center for handy operation by astronaut on duty. It is placed opposite the control console allowing a more favorable mass distribution of the laboratory. Since

water is the chemical bi-product of the fuel cell, its location allows gravity flow to the rest room below and the galley by its side. No pumping is necessary. Also, shorter, lighter-weight lead lines result from the power source being near the equipment.

The galley is located on the upper floor which is away from the sanitary facilities but near the electrical power supply operating the food locker and stoves. Fumes from the stove must be carried to the air conditioning system by special vent covers to prevent contamination of the cabin air of greases and lingering odors.

Volumes and floor areas of the space laboratory compartments are tabulated in Table 3.

TABLE 3 INTERNAL VOLUMES AND FLOOR AREAS OF SPACE LABORATORY

ITEM	LOCATION	FLOOR AREA (SQ.FT)	VOL. OCCUPIED (CU.FT.)	% OF TOTAL VOL. (1200 CU.FT.)
Control Console Area	Cabin upper floor	25.5	175	14.6
Control Room Clear Area	Cabin upper floor	23.0	170	14.2
Food Center	Cabin upper floor	5.5	33	2.7
Food Locker	Cabin upper floor	3.5	21	1.8
A.P.U. Compartment	Cabin upper floor	4.5	27	2.3
Storage Locker	Cabin upper floor	5.0	32	2.7
Work Bench	Cabin upper floor	3.0	20	1.7
Bathroom	Cabin lower floor	12.8	100	8.3
Life Support Compartment	Cabin lower floor	12.8	100	8.3
Recreation Area	Cabin lower floor	44.4	327	27.2
Storage and Sump	Under lower floor	—	45	3.7
Air Lock	Above cabin	—	20	1.7
Sleeping room	Re-entry capsule	—	130	10.8
TOTALS		140.0	1200	100.0

Cabin Atmosphere

An important function of Tassel is to determine the limits of human capability when varying the cabin atmosphere. Although humans can tolerate a great variation in their environment, it will not be possible to obtain satisfactory answers to the extent of these limitations until an actual space vehicle is operating at zero or reduced gravity.

It appears desirable for space stations and especially long range interplanetary vehicles to reduce the cabin pressure to 5.5 psia. This would require nearly 100% oxygen with perhaps a slight dilution if necessary. Talking would be more difficult but fire hazard would be about equal with that of 1 atmosphere since the oxygen partial pressure is about the same in either case. The following is a list of advantages in using 5.5 psia cabin pressure:

1. Reduces mixture control problems of oxygen and inert gas.
2. Eliminates having to carry large make-up tanks of inert gas.
3. 5.5 psi is a compromise between 3 psi pure oxygen which is the lower limit of suffocating and 7 psi which becomes toxic.
4. Structural integrity can more easily be maintained with explosive decompression having lower pressure.
5. Structural design at lower pressure.
6. Cabin leakage will be less with less pressure.

Although 5.5 psia appears to have certain beneficial advantages, its merits have yet to be proven by actual test. For prolonged periods at zero or reduced gravity, it appears best, until otherwise substantiated, to design for environmental control inside the space cabin compatible with the requirements of the astronauts as they experience at sea level under 1 atmosphere.

The environmental unit (air conditioning and atmospheric control) must be capable of simulating and automatic maintaining moderate terrestrial conditions of atmospheric pressure, temperature and air composition. By weight, the oxygen concentration must be controlled to about 25% (± 5%); nitrogen concentration 75% (± 5%); CO_2 concentration below 0.5%; CO from smoking 0.005% max; temperature 70° F (± 10° F) and relative humidity, depending on the temperature, about 35% (± 10%). The air conditioning units and atmospheric control equipment must be capable of continuous operation at any G-level.

Heat loads in the cabin are considered to be primarily created by the astronaut's activities, the electrical energy consumed and the heat of reaction in the fuel cell. The amount of heat transferred from this outer surface through the insulation to the cabin is regarded as minor. It is anticipated that most, if not all, heat intercepted by the outside shell will be reflected or radiated. External sources include solar and earth radiation, evaporation of

stored liquids, Van Allen radiation, etc.

To remove heat from the cabin's interior, large exterior radiators are provided. The process operates by passing cabin air through an exchanger where its heat is carried to the external radiators by a refrigerant (perhaps water). Shutters shade the radiators from the sun as well as providing a control for this refrigerant temperature.

Ventilation

General commercial aircraft practice provides 20 cu. ft. of air per minute per passenger. Keeping with this established practice -- the space cabin air with 1200 cu ft. volume would be changed every 20 minutes or 3 times during an hour. The air is circulated through ducts of ample size so the flow is kept low in the ducts and far below draft level in the living and working areas.

If the air conditioning unit should cease functioning 1200 cu ft. of air of standard atmosphere would contain about 24 cu ft. of oxygen per astronaut. This would allow an unacclimatized astronaut to carry on light repair work for 12 hours before the oxygen partial pressure drops below the 115 mm Hg minimum where oxygen masks must be used.

Heat Load Calculations

The following estimate of cooling load gives the amount of air required for circulation and the amount of refrigeration required

to maintain proper living conditions. It is assumed that in an average situation, one astronaut would be resting while the other two are working. Under reduced gravity it can be expected that only mild work energy will be required. Therefore,

1 astronaut	resting	=	380 BTU/hr
2 "	working	=	860 " "
Astronaut Total		=	1240 " "

The fuel cell is assumed to be 65% efficient, therefore, of the 850 watt output the fuel cell is generating $\frac{850}{.65}$ = 1310 watts of total energy or 1310 - 850 = 460 watts by heat of reaction.

460 watts x 3.413	=	1570 Btu/hr
850 " x "	=	2900 " "
Total fuel cell energy		4470 " "

With cabin conditions to be maintained at 70° F, 35% relative humidity and assuming air velocities of 15 to 25 fpm, the A.S.H.V.E. comfort chart gives,

wet bulb = 55° F

effective temp. = 65° F

Of the 1240 Btu/hr from the astronauts a portion is given up as latent heat by moisture evaporated into the cabin air and a portion is given up as sensible heat. At 70° F, the heat loss by evaporation is 100 Btu/hr/astronaut (men seated at rest from A.S.H.V.E. Handbk) or 760 grains of moisture/hr/astronaut.

Latent heat = 3 x 100 = 300 Btu/hr

Moisture = 3 x 760 = 2280 grain/hr

The sensible heat loss from the astronauts = total loss - latent heat loss

= 1240 - 300

= 940 Btu/hr

or $\frac{940}{1240}$ = 76% of total loss

The total cabin sensible heat rates with 25% added for peak outputs

= (astronauts + fuel cells) 1.25

= (940 + 4470) 1.25

= 6760 Btu/hr

Since the cabin is provided with three air changes per hour there are 1200 x 3 or 3600 cu/ft. of air pumped through the air conditioning system per hour to maintain the 70° F and 35% relative humidity.

3600 cu. ft. of air weighs;

$$w = \frac{PV}{RT} = \frac{(14.7 \times 144) \times 3600}{53.34 \times (70 + 460)}$$

$$= 270 \text{ lbs.}$$

The temperature difference (Δt) between incoming air from the conditioner and cabin air in order to handle the sensible heat load of 6760 Btu/hr is calculated from;

$$Qs = W\ Cp(\Delta t)$$

$$\Delta t = \frac{Qs}{W\ Cp}$$

$$= \frac{6760}{270 \times 0.24}$$

$$= 10^\circ \text{ temperature difference}$$

thus, the duct air must be 60° F. In order to retain 35% relative humidity in the cabin the air conditioning system must remove 2280 grains of moisture per hour and the moisture removed per pound of air = $\frac{2280}{270}$ = 8.45 grains. Thus, from a "psychrometric chart" duct air must enter the cabin at 60° F and 39% relative humidity. Wet bulb temp. of 48° F in order to provide cabin comfort of 70° F and 35% relative humidity.

The 2280 grains (0.326 lbs.) of water per hour can be removed by the high capacity magnesium perchlorate $Mg\ (Cl\ O_4)_2$ or other dessicants such as calcium oxide, silica gel or Linde molecular sieves. Between 2 to 3 lbs of $Mg\ (Cl\ O_4)_2$ are required to remove 1 lb. of water. Thus, from 0.65 to 0.98 lbs. of the chemical are required per hour or from 324 to 494 lbs. for the three week period. This being far too expensive to carry the total weight, a smaller amount of the chemical could be carried with provisions for regeneration. This can be done by exposing a portion of the

chemical to the outside vacuum while another portion is in operation. Or, by letting this humidity raise during short periods of regeneration.

Another possibility might be to harness the reaction heat from the fuel cell and use it to drive a refrigeration system that will precipitate moisture from the air as well as cool. The refrigerant would be cooled in the external radiators radiating to space at approximately 180° R and toward earth at approximately 400° R. Shutters close when directed toward the sun.

To maintain the cabin temperature at 70° F, the air must be pumped through a heat exchanger and cooled to 60° F.

Air Leakage

Every reasonable precaution will have to be taken to develop an air-tight space cabin. A special rubberized nylon inner liner will serve to contain the cabin air. If weight permits, this liner may be self sealing. In spite of the precautions taken, it is believed that it is very improbable that a 100% permanent sealing of the cabin can be relied upon. Many fittings and connections pass through the liner and during ascent, the vehicle will be rocked and vibrated severely. This will create strain on the inner liner and may possibly develop infinitesimal small joint leakage. The air lock doors and the joint between the re-entry vehicle and the cabin also lend themselves as possible sources for leakage. Although the amount of leakage is arbitrary, some allowance must be made in the air requirements to handle such losses.

For example, assume a hole the diameter of a fine hair (say half-thousandth of an inch) exiting air from the cabin at one atmosphere to vacua outside. Assume also that the hole has a nozzle coefficient of unity, allowing the air to escape at sonic velocity. This is a conservative assumption, but illustrative. The area of the hole would be about 10^{-4} sq. inches and the volume of air escaping would be:

$$\begin{aligned} V &= A\,v_s \\ &= 10^{-4}/144 \times 1100 \\ &= 7.64 \times 10^{-4} \text{ cu ft/sec} \end{aligned}$$

The unit weight of the escaping gas at 1 atmosphere and 70° F is,

$$\dot{W} = \frac{PV}{RT} = \frac{14.7 \times 144 \times 7.64 \times 10^{-4}}{53.3 \times 530}$$

$$= 5.72 \times 10^{-5} \text{ lbs/sec.}$$

For a 21 day mission the total weight of escaping air would be,

$$W = 5.72 \times 10^{-5} \times 86{,}400 \times 21$$

$$= 104 \text{ lbs}$$

If the pressure were reduced to 5.5 psia, then, there would be only 39 lbs of air escape under the same conditions.

Since the cabin will probably be operated part of the time at 14.7 and part at 5.5 psia, the average weight of escaped air would be about 70 lbs. Five pounds will be needed for the increased size of the air supply container, thus resulting in a weight cost of 75 lbs for extra air.

Space Capsule Tasc

The Three Astronaut Space Capsule, Tasc, is designed along the same basic lines as the NASA Mercury type capsule rather than along the lines of a glide vehicle. Although a glide vehicle possesses certain advantages such as better control and reduced deceleration during re-entry, it has large surface areas which makes the vehicle larger and heavier than the ballistic type. However, some modifications such as adding control flaps may be attached to the basic ballistic capsule to provide some degree of lift and control. But, until the technology of constructing light-weight glide vehicles has been achieved, it appears to be most likely that payload demands will favor the lighter weight ballistic body such as shown in Figure 4 and Figure 5.

This design draws on the information, experience and technology available from the Mercury and ballistic missile programs. It allows a more desirable tradeoff of payload, permitting either a larger crew or flights of longer duration.

The space capsule's primary function is to protect the astronauts during ascent and during re-entry. The capsule is considered to be simply designed, compact and easy to develop. Its configuration is predicted on the capsules usage with advanced space programs such as the space laboratory, Tassel, rescue and recovery operations, rendesvous experiments, manned photo reconnaissance programs, lunar encounters, etc, where it is desirable to have a multi-astronaut capsule.

Tase is designed similar to the one-man Mercury capsule. Its main configuration difference is in its larger body for housing 3 astronauts and its possession of two access doors; one in the center on top surrounded by parachute canisters and the other on the conical frustum portion of the capsules side. There will be system differences such as in electronics, the life support system and structure since advancements in the state-of-the-arts have brought forth new ideas and knowhow. Also, the capsules more generalized purpose and its extended mission periods will introduce certain functional differences that will dictate arrangements and modifications to the basic capsule, depending on the capsule's prescribed mission.

Since re-entry is the greatest design consideration a flat curvature heat-shield of the ablative type is shown. To be aerodynamically stable during re-entry, the capsule must have its center of gravity forward of its center of pressure. The astronauts and the heavier internal equipment must therefore be located as close to the heat shield as possible.

Tests have shown that man can take acceleration loads against his back better than in other directions. Therefore, the astronauts must experience the ascent acceleration and the re-entry deceleration in a supine position. This dictates their position in the capsule and the capsules attitude relative to the booster.

For capsule stability and reduction in heating during re-entry, a cone shaped afterbody appears most desirable. The apex of the cone must be modified somewhat for a center access door and canisters containing parachutes for the final descent.

Since safety of the astronaut is paramount, there must be a dependable escape system for use during launching and booster ascent. This is provided by using emergency rockets to launch the capsule off from the missile's nose. Placement of these escape rockets to prevent blast impingement on the capsule and the booster tank structure and to obviate undesirable overturning moments requires clustering of the rockets into one package placed on a tower above and away from the capsule. The nozzles of the escape rocket will be canted to eliminate the main blast from striking the capsule. The centerline of thrust is at a small angle with respect to the missiles centerline providing enough side component to send the capsule off at an angle thus allowing during escape, a safe margin of clearance with the ascending missile. Another basic purpose of the tower is to provide stability in forward flight during escape by moving the center of gravity away from the heat shield and toward the escape rocket. The tower is jettisoned after successful ascent and the center of gravity then moves back near the heat shield, where it is best located for re-entry.

The capsule during ascent and re-entry will utilize an open or semi-open ecological system based on stored food, water, oxygen, etc., and on existing electrical and communication systems. During orbital stay, the ecological system of the parent vehicle will supply the capsule with atmosphere and power.

Since Tasc is too heavy for the Atlas alone to place into orbit, it is necessary that an upper stage be used. Figure 6 shows the capsule being launched by an Atlas/Centaur. The more than sufficient impulses available by the Centaur makes it an ideal upper stage for perfecting orbital rendezvous missions since it can allow trial and error operations in orbit. The table below gives the approximate weight of the re-entry capsule Tasc.

	Without Astronauts	With Astronauts
Launch Condition	4400 lbs	5000 lbs
Orbital Condition	3400 "	4000 "
Entry Condition	2800 "	3400 "

Note: Orbital condition is less the escape tower and rockets.
Entry condition is less the retro-rockets.

Rotating System Analysis

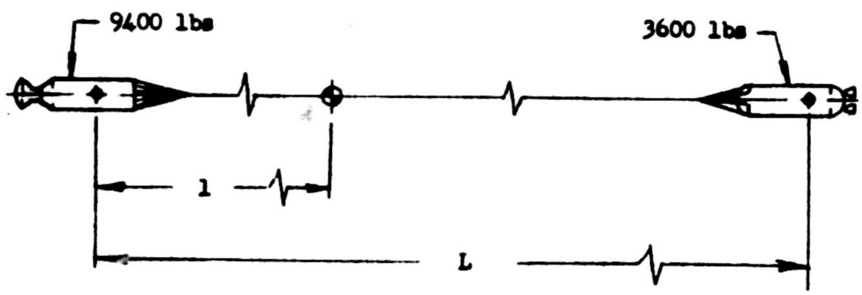
Since one of Tassel's prime purposes is to establish man's physiological and psychological limits in space, it is necessary that the vehicle have as much versatility as possible to support such experiments. One important characteristic of Tassel broadening its usefulness is its ability to provide and vary the G-level in the space cabin. G-level is accomplished by cable connected masses rotating about their common center of mass. One of the masses is the space laboratory while the other is the empty Centaur tank. When the system is provided with angular velocity, a G-level is produced. The G-level depends upon the length of the cable system and the velocity of rotation. When the system is rotating and the connecting cable is shortened, by conservation of momentum, the system increases its angular velocity which is accompanied by an increase in the G-level. Tassel has a winch on the cable to provide variation in G-level.

The following section discusses quantitatively the characteristics of rotating the cable connected bodies about their common center of mass.

Atlas/Centaur is capable of delivering about 13,000 lbs into a 200 n. mi. orbit (Figure 7) of which part is payload and part is the Centaur stage. The resolved weights of the payload and the Centaur are about 9,400 and 3,600 lbs respectively. (This is

estimated on the basis of the 3,750 lb Centaur where included are: 93 lbs of autopilot, 157 lbs of guidance, 20 lbs of inverter and power change-over equipment, 30 lbs of batteries, a 20 lb transponder and 275 lbs of special installations for Tassel such as cable, cable attachments, rotational rockets reinforcements, controls, etc. Removed from the basic Centaur are: 39 lbs of range safety, 303 lbs of telemeter equipment and 90 lbs of batteries.)

The common center of mass of the Tassel system is shown in Figure 10.



$$l = \frac{3600}{13,000} L = 0.277 L$$

Figure 10

Center of Mass

. The systems moment of inertia about the common center of mass is:

$$J_m = \frac{9400}{32.2}(0.277L)^2 + \frac{3600}{32.2}(0.723L)^2$$

$$= 22.4\ L^2 + 58.5\ L^2$$

$$= 80.9\ L^2\ \text{sl - ft}^2$$

Note: For simplicity, the moment of inertia of the individual masses about their own C.M. is regarded as negligible. A plot of the system's moment of inertia is shown below.

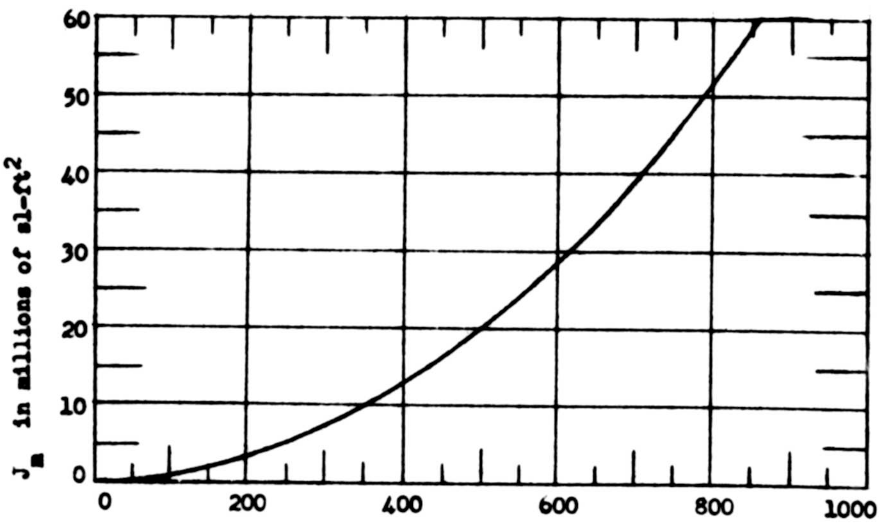


Figure 11

Tassel System Moment of Inertia

Since the system is in a zero-G environment while orbiting, the only gravity created within the capsule is produced by the centrifugal force of the system rotating about its own center of mass. The artificial gravity created as a function of angular velocity and system length is formulized from the centrifugal force equation ($F = m\omega^2 r$) equated against the force in the second law of motion ($F = ma$) i.e.,

$$m\omega^2 r = m a$$

$$a = \omega^2 r$$

where:

a = acceleration (ft/sec^2)

ω = angular velocity (rad/sec)

r = radius of rotation (ft)

To express the artificial acceleration G in the cabin of Tassel in terms of rpm and system length L:

$$\omega \text{ (rad/sec)} = 0.1047 \text{ (RPM)}$$

$$r = 0.277 \text{ L}$$

$$G = \frac{a}{32.2} = \frac{\omega^2 r}{32.2}$$

$$G = \frac{[0.1047 \text{ (RPM)}]^2 \; 0.277 \text{ L}}{32.2}$$

$$G = 9.41 \text{ (RPM)}^2 \text{ L} \times 10^{-5}$$

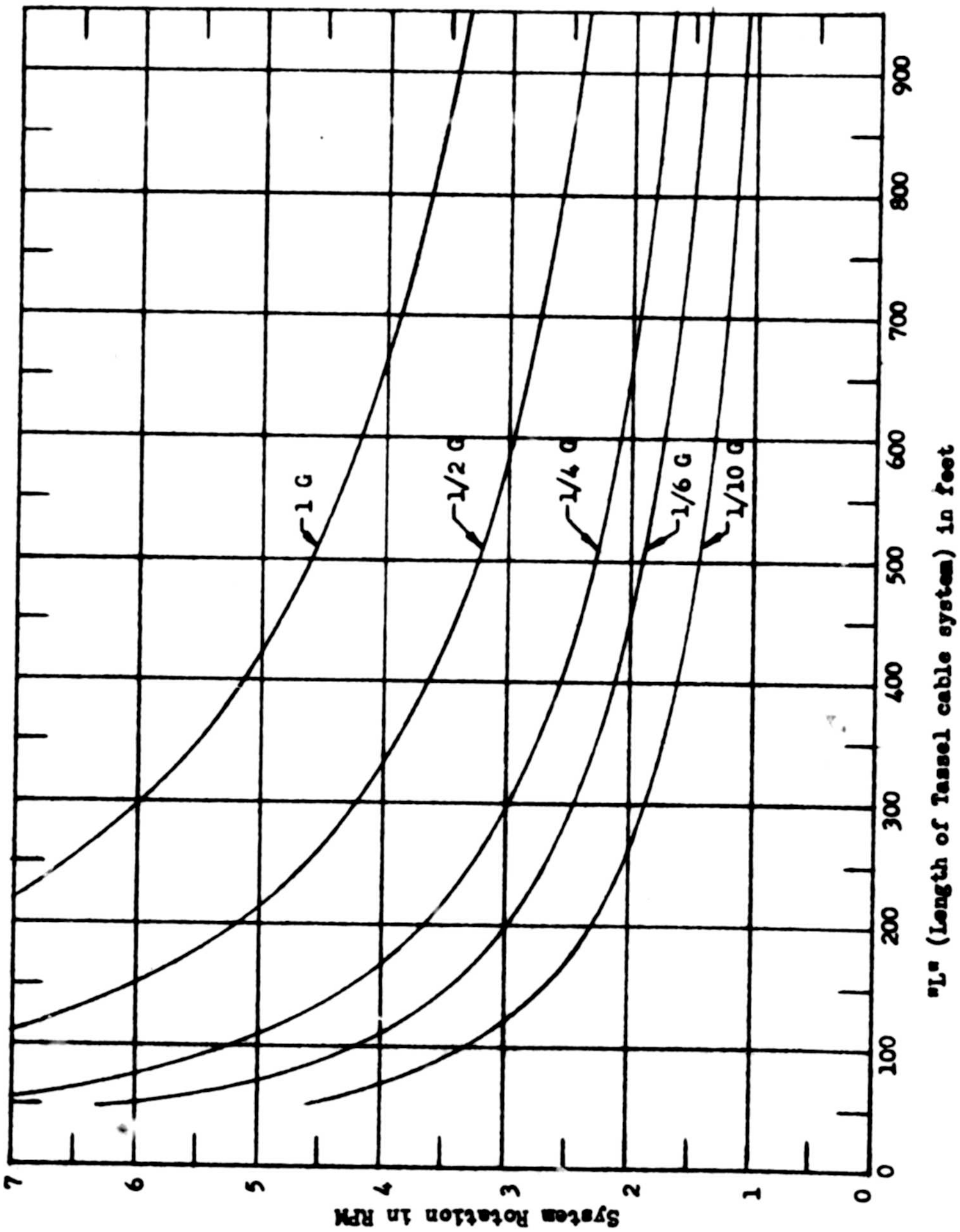


Fig. 12 Artificial Gravity Level

The rotational velocity of the system as a function of system length for various induced G-levels is shown in Figure 12. It should be noted that the acceleration at the Centaur tank is 2.61 times that in the cabin since its radius is this factor greater from the system's center of mass.

Once the space laboratory is set into rotation it will maintain a constant angular velocity and provide a steady artificial gravity. However, it may be desirable to produce a greater or less gravity level if a particular test requires, or if necessary, to provide a higher gravity level to condition the crew members for their return trip thru the atmosphere. To accomplish the task of varying the gravity, a winch is placed on the cable. It can reel in and shorten or reel out and lengthen the cable. Since a constant angular momentum is maintained in the system, reeling in the cable will tend to increase the rotational velocity and in turn increase the gravity level.

The angular momentum of the system is:

$$\mathcal{M} = J_m \omega \quad sl - ft^2/sec$$

J_m = systems moment of inertia $sl - ft^2$

ω = angular velocity rad/sec.

$$J_m = 73.2 L^2 \text{ for Tassel}$$

$$\mathcal{M} = k_1 L^2 \omega$$

The gravity level (G) produced by rotation is:

$$G = \frac{a}{32.2} = \frac{\omega^2 r}{32.2}$$

r = radius to center of mass = $K_2 L$ then, $G = k_3 \omega^2 L$

from which

$$\omega = k_4 \left(\frac{G}{L}\right)^{\frac{1}{2}}$$

substituting in above equation angular momentum may be expressed in terms of G-level and cable length of system.

$$\mathcal{M} = k_1 L^2 \ k_4 \ \left(\frac{G}{L}\right)^{\frac{1}{2}}$$

$$= k_5 \ (GL^3)^{\frac{1}{2}}$$

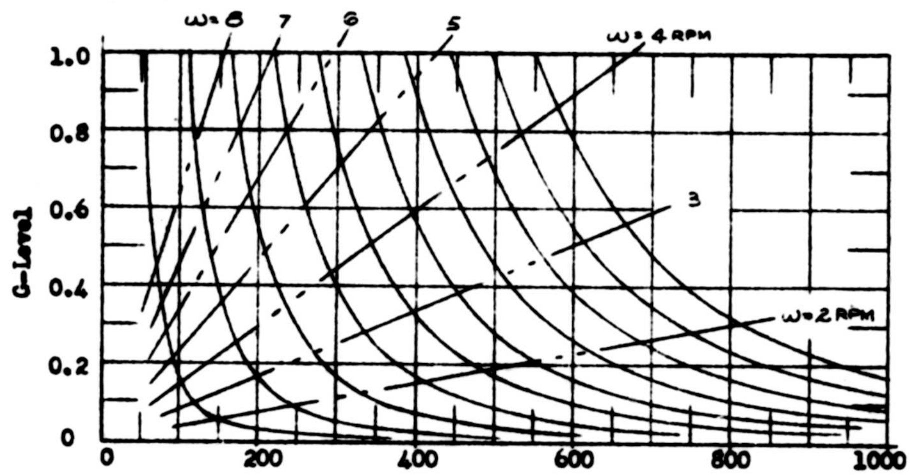
(note: for Tassel $k_5 = 820$)

By equating the angular momentum of the system's initial conditions with the angular momentum of a new cable length and new G-level, the new cable length (L_n) is derived as:

$$\mathcal{M} = \mathcal{M}_n$$

$$k_5 \ (GL^3)^{\frac{1}{2}} = k_5 \ (G_n \ L_n{}^3)^{\frac{1}{2}}$$

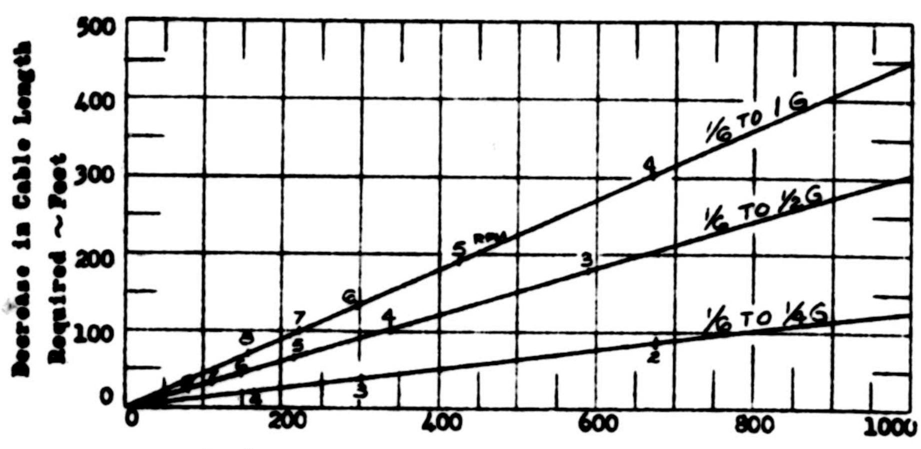
$$L_n = L \left(\frac{G}{G_n}\right)^{1/3}$$



L (Length of cable system) in feet

Figure 13

Constant Angular Momentum Curves



L (Length of cable system) in feet

Figure 14 Decrease in Cable Length Required to Increase G-Level from 1/6 G

thus, if initial conditions were L = 500 ft cable and 1/6 G, then, to produce 1 G, the cable length must be:

$$L_n = 500 \left(\frac{1/6}{1}\right)^{1/3}$$

$$= 275 \text{ ft.}$$

The plot below shows the effect on gravity by varying the cable length for various constant angular momentums.

Energy of Rotating System:

The Tassel system by nature of its rotation possesses kinetic energy. This energy must be imparted to the system by rockets. To compare the energies of various rotational diameters and G-levels the following quantitative analysis is made:

$$K.E. = \tfrac{1}{2} J_n \omega^2 \text{ ft-lbs}$$

J_n = systems moment of inertia

= $80.9\ L^2$ (for Tassel)

ω = systems angular velocity in rad/sec.

= 0.1047 (RPM)

G = $9.41\ (RPM)^2\ L \times 10^{-5}$

$$\text{then,}\quad K.E. = \tfrac{1}{2}\,(80.9\,L^2)\,(0.1047\ RPM)^2$$

$$= 0.442\,L^2\,(RPM)^2$$

$$= 0.442\,L \left(\frac{G \times 10^5}{9.41\,L}\right)$$

$$= 4700\,L\,G \qquad (\text{ft-lbs})$$

where L = length of system (ft)

G = gravity level (g^s)

A plot of the kinetic energy for the rotating mass system is depicted in Figure 15 below.

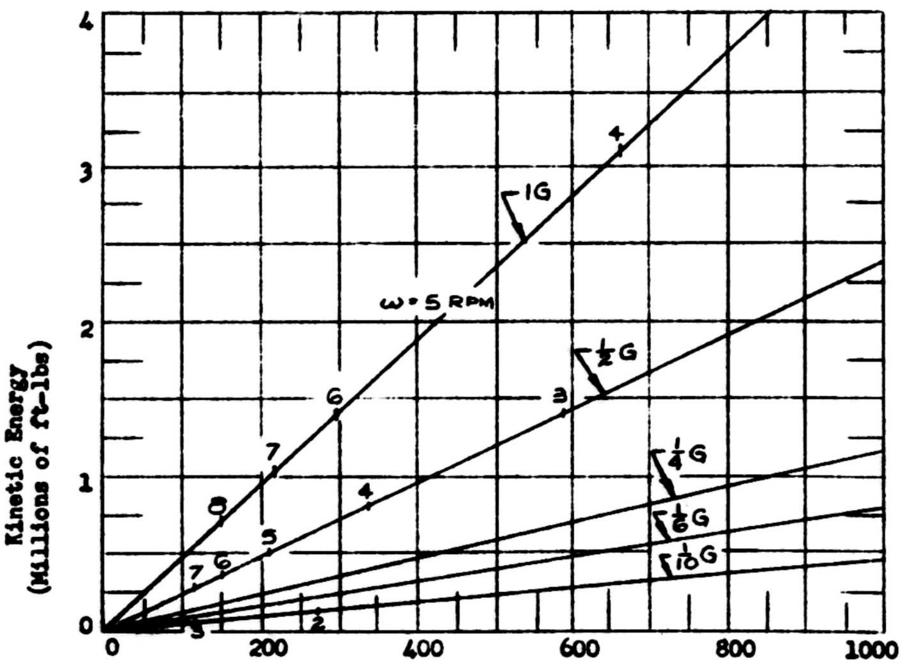


Figure 15 Kinetic Energy of Rotating Tassel

To rotate the two masses, thrust must be applied normal to the cable centerline. Since 50 lb hydrogen peroxide units are already designed for the Centaur. These would be satisfactory units to use. In reality, it may not be desirable to place a thrust unit on the cabin as well as on the Centaur tank, but for this analysis, it is assumed there is thrust imparted to both bodies. 50 lbs of thrust is applied to the Centaur tank at 0.723 L feet from the center of rotation (center of mass). Its moment of inertia about the C.M. is $J_t = 58.5\ L^2$ sl-ft^2. The cabin is 0.277 L feet from the C.M. with a $J_c = 22.4\ L^2$. The amount of thrust (F) required at the cabin to provide same angular acceleration (α) and angular velocity (W) as the Centaur tank system is:

$$F = \frac{T\ (\text{torque})}{r\ (\text{radius})} = \frac{J\alpha}{r}$$

then,

$$\alpha = \frac{F\,r}{J}$$

or

$$\frac{F_c\,r_c}{J_c} = \frac{F_t\,r_t}{J_t}$$

$$F_c = F_t \times \left(\frac{r_t}{J_t}\right) \times \left(\frac{J_c}{r_c}\right)$$

then,

$$F_c = F_t \times \left(\frac{0.723\ L}{58.5\ L^2}\right) \times \left(\frac{22.4\ L^2}{0.277\ L}\right)$$

$$F_c = F_t\ (1)$$

Therefore, the thrust at the cabin is the same as the thrust at the Centaur, i.e., 50 lbs. normal to the radial centerline. The acceleration of the system with 50 lb thrust units mounted on each body is,

$$\alpha = \frac{F_t r_t}{J_t} = \frac{F_c r_c}{J_c}$$

$$= \frac{50 \times 0.723 \text{ L}}{58.5 \text{ L}^2}$$

$$= 0.618 \quad \frac{1}{L}$$

The total impulse (I_t) of the system in terms of RPM and length of cable systems (L) is,

$$I_t = (F_t + F_c)\ t$$

$$t = \text{duration time of firing}$$

$$= \frac{\omega}{\alpha} \text{ (rad/sec)}$$

$$= \frac{(0.1047 \text{ RPM})}{0.618 \frac{1}{L}}$$

then for Tassel, $I_t = 2\ (50) \quad \dfrac{0.1047 \text{ (RPM) L}}{0.618}$

$$= 16.9 \text{ (RPM) L}$$

or $\quad I_t = 1740 \sqrt{GL}$

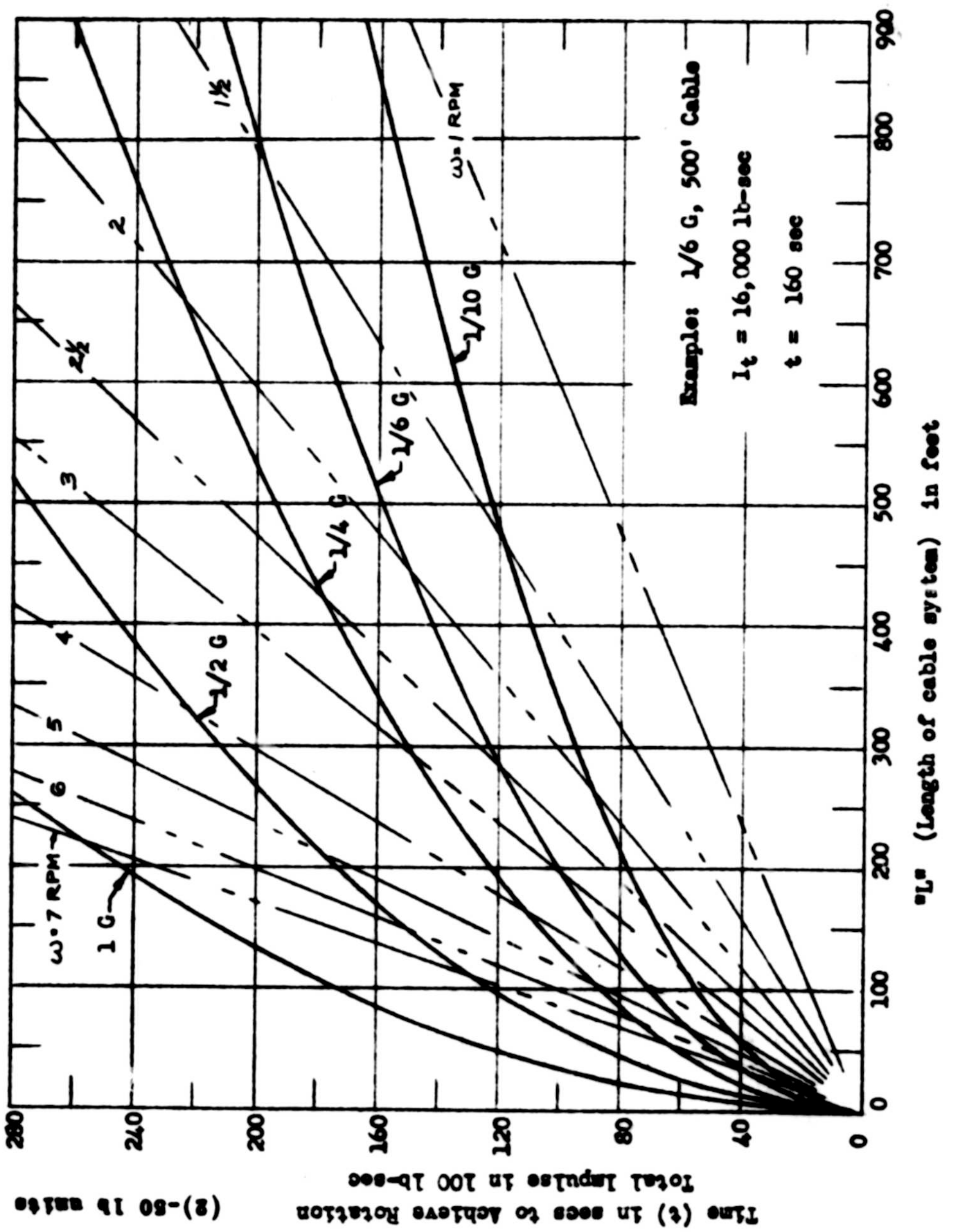


Fig 16 Total Impulse and Time to Achieve Rotation

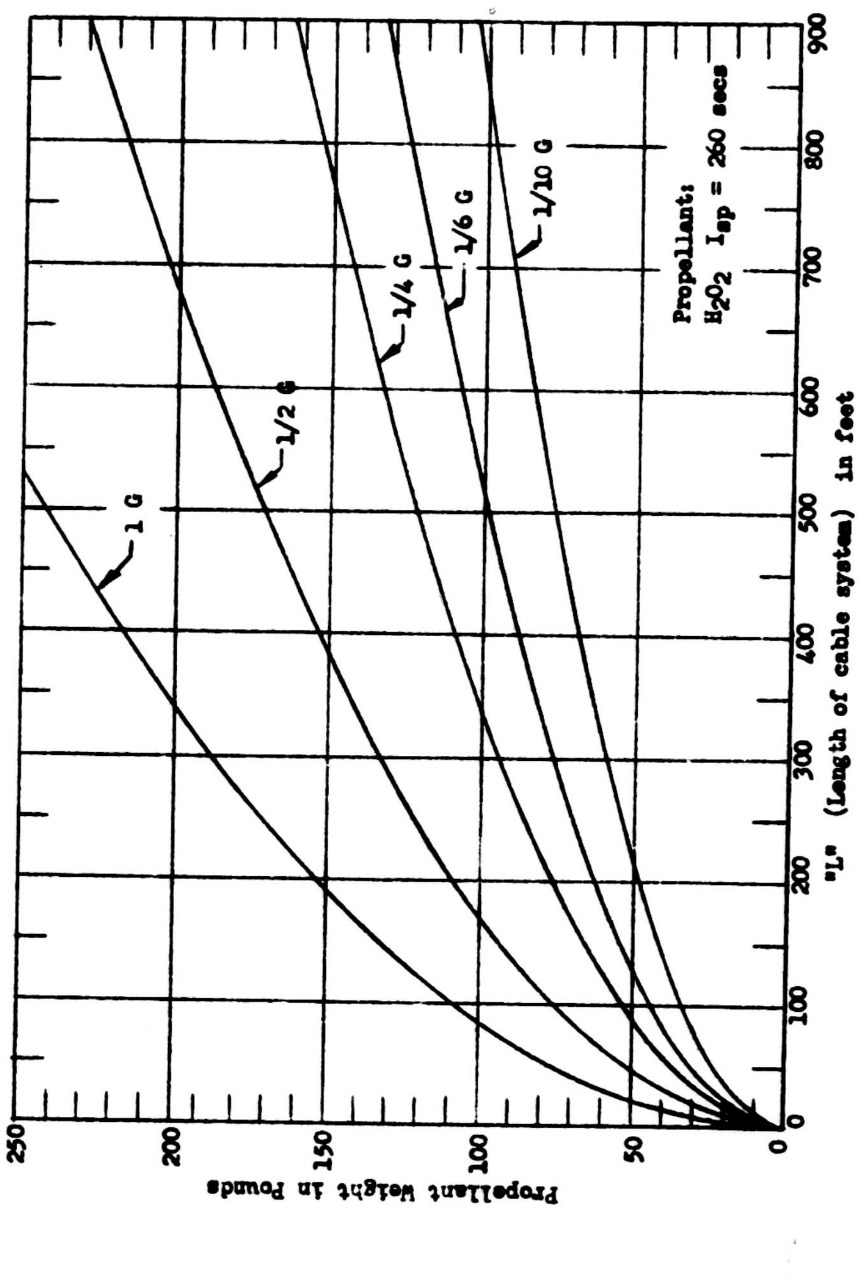


Fig 17 Propellant Weight Required to Initiate Rotation

The time (t) to arrive at the desired RPM with two 50 lb thrust units is,

$$t = \frac{I_t}{F} = \frac{I_t}{2 \times 50} = \frac{I_t}{100} \text{ (SECS)}$$

I_t and t are plotted in Fig. 16 and Propellant weight required plotted in Figure 17 against L.

It should be noted that a considerable reduction in propellant may be realized if the cable is long when initiating rotation, then, shortening to increase the G-level. For example, initiating 1/6 G with a 500 ft cable requires 98 lbs of H_2O_2 propellant Fig. 17. From the constant angular momentum curves (Fig. 13) by shortening the cable with a winch after achieving 1/6 G by rockets, from 500 to 275 feet, 1 G can be realized in the cabin. However, if 1 G were to be required with no shortening of the cable, then from Fig. 16 180 lbs of H_2O_2 would be necessary. This is 82 lbs less H_2O_2. Of course, the weight of the winch and the power to operate must be included to provide a ~~more~~ realistic comparison.

Assuming a winch with a capacity of 5 tons (sufficient to handle 1 G at the cabin) provided with an electric motor. The hoist would have a worm drive to lock the drum in any position where the motor stops. Assumed is a 60:1 gear ratio ~~winch~~ with a 6 inch average diameter drum and a cable capacity of 225 ft. The input motor is assumed operating at 120 rpm with an efficiency of 86%. According

to the De Laval Company, their emperical formula for worm gearing for best thrust bearings is $e_w = 1 - 0.005\, r_v$ where r_v = speed ratio of worm and gear. Thus for 60 to 1 $e_w = 1 - 0.005\,(60) =$ 0.70 or 70%. The combined efficiency of motor and winch is then,

$$e = e_w \cdot e_M = 0.70 \times 0.86 = 0.60 \text{ or } 60\% .$$

Each rpm the drum reels in $\frac{\pi}{2}$ = 1.57 ft. With a 120 rpm motor, the cable reels in $\frac{120}{60} \times 1.57 = 3.14$ ft per minute which would require a time period of $\frac{225}{3.14} = 72$ minutes to shorten the cable from 500 ft. at 1/6 G to 275 ft at 1 G. From Fig. 13, the average G-level with respect to operating time is approximately .38 G. The average weight moved by the winch would be 9400 lbs x 0.38 = 3570 lbs. The work done by the winch is 3570 x 3.14 = 11,200 ft-lbs/minute or 11,200/33,000 = 0.34 HP . The electric motor would require an input of $\frac{0.34}{0.60}$ = 0.567 HP or 422 watts for 72 minutes (0.5 KWH). The peak load will occur as the system is approaching the 1 G condition at end of run where the power required is 844 watts. This is close to the 850 watt output of the electrical power fuel cell.

The weight of the winch, motor, electrical cable and control is assumed to be about 50 lbs. The O_2 and H_2 fuel and tankage for 0.5 KWH burned in the fuel cell to provide power to the winch would be about 2 lbs. 225 feet of 3/8 cable 7 x 19 (breaking strength of 14,400 lbs gives 50% safety margin) weighs 48 lbs with fittings. The total weight of the winch system with the extra 225 feet of cable weighs approximately 100 lbs.

As mentioned in the example above, 180 lbs of propellant would be required to initiate 1 G spin with a 275 foot cable system. On the other hand, with a winch system it requires only 98 lbs of propellant to initiate spin to 1/6 G with a 500 foot cable, then, by reeling in this cable to 275 feet, a 1 G level is achieved. However, as calculated above, approximately 100 lbs for the winch system must be added to the 98 lbs making the winch system about 18 pounds heavier than the direct cable system.

The above example is calculated for only one condition but serves to point out that by adding a winch to the cable system the versatility feature of changing G-levels may be had at relatively small if any additional cost to the overall weight.

Coriolis Acceleration

This acceleration is a phenomenon that is created when a body is moved parallel to the radial axis of a spinning system. When the body moves the acceleration acts perpendicular to the direction of the body's motion. An example which most everyone has experienced is the act of walking toward or away from the center of a merry-go-round, while it is in motion. A person tends to veer sideways and lose his balance. The effect depends upon the merry-go-rounds period of rotation and the velocity of the persons motion toward or away from the hub. In space station design, the coriolis acceleration may become rather annoying to an astronaut if he is producing his

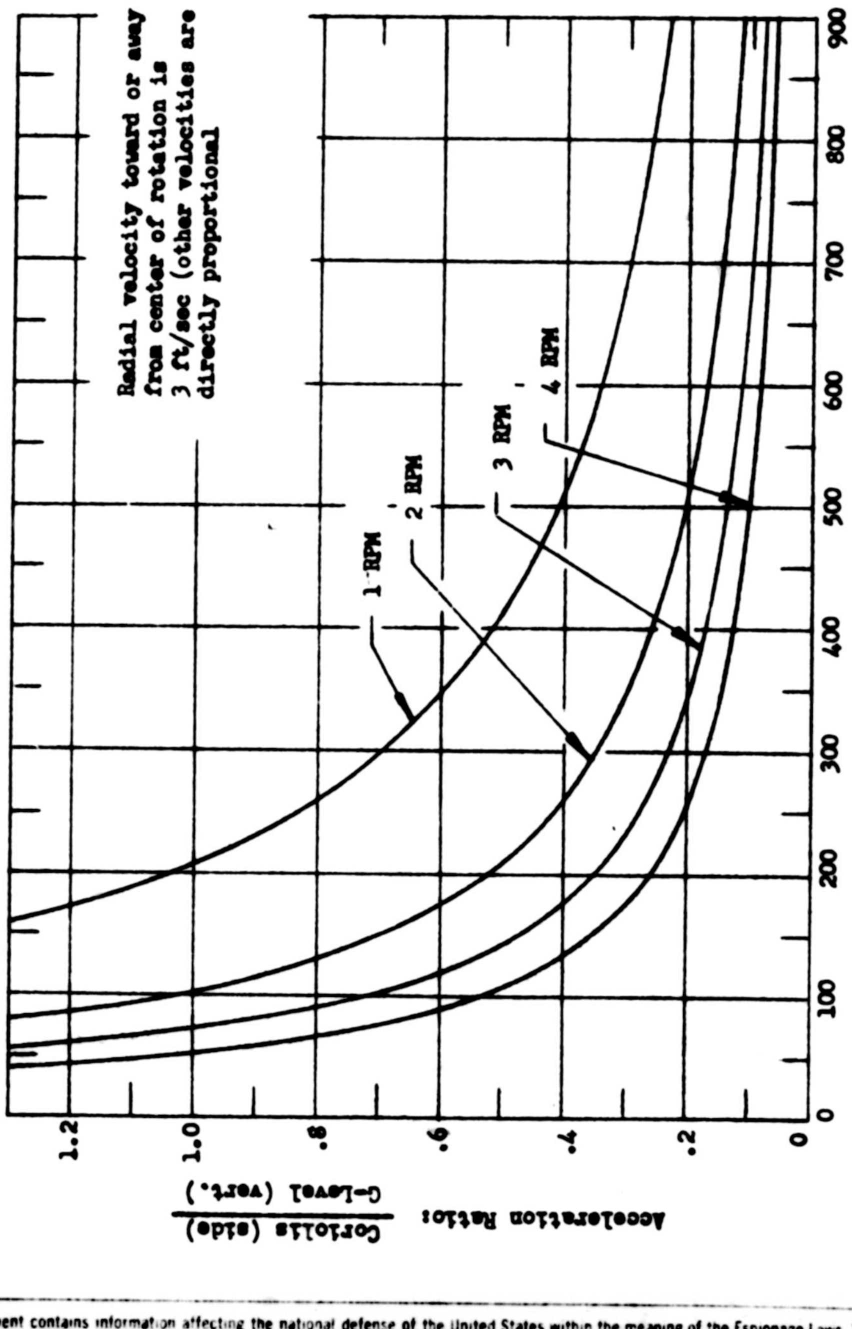


Fig. 18 Ratio - Coriolis (side) to Vertical Accelerations

vertical acceleration by high rpm about a short radius. In the design of Tassel, a long cable would provide sufficient vertical acceleration with a slow period of rotation, thus, the Coriolis acceleration would be reduced to a reasonably low level.

In moving from one floor to another in Tassel or moving one's hand up or down while operating controls, a motion of 3 ft/sec is believed an average velocity to be considered in calculating the Coriolis acceleration. The following curves show the effect of Coriolis acceleration as a function of the space lab's RPM. It is based on the formula

$$a = \frac{4\pi}{T} v$$

T = period of revolution (secs)

v = radial velocity (ft/sec)

a = Coriolis acceleration (ft/sec^2)

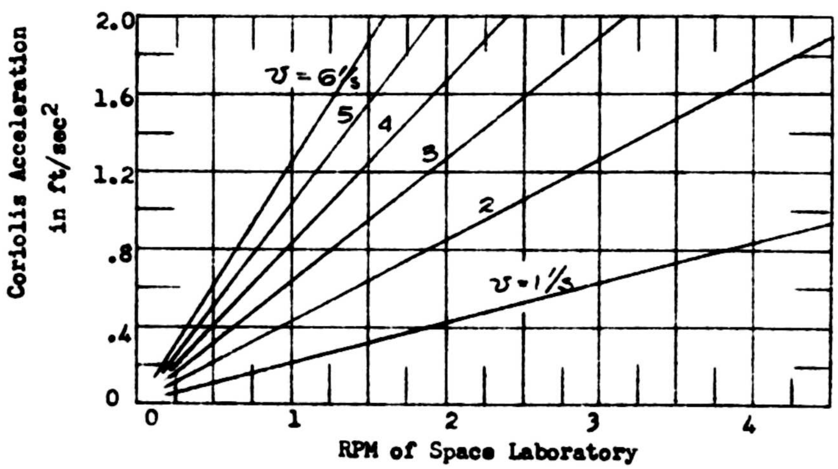


Fig. 19 Coriolis Accel. vs RPM for various radial velocities

An example with the aid of the graph above: An astronaut in a space station rotating at 2 rpm raises his hand vertically 3 ft/sec towards an object 3 feet directly above. If he did not restrain his motion, his hand would tend to veer ($S = \frac{1}{2} at^2 = \frac{1}{2} \times 1.26 (1)^2 = 0.63$) $7\frac{1}{2}$ inches to the objects side.

To further the discussion, suppose the astronaut under low vertical acceleration is jumping from the lower floor to the upper thru the hatchway. If he is not cautious he could veer sideways enough to bang himself against the side of the hatchway or perhaps crack his head on an obstruction above.

Although Coriolis acceleration will be present at any angular velocity, its effect is more noticeable at lower gravity levels. For instance the space station Tassel rotating at 2 rpm with a cable system 27 feet long would produce 0.01 G. The Coriolis acceleration at 3 ft/sec radial velocity at 2 rpm is 0.039 G or almost 4 times the vertical. With this criteria, an astronaut supposedly jumping vertically would in reality veer off on a 75° angle with his vertical. This example may be an extreme case, but refering to Figure 18. which is a graph of Coriolis acceleration to vertical acceleration for various length cable systems and various rpm, the Coriolis effect as shown is very considerable with short cable lengths. At 2 rpm with a 100 foot cable system the Coriolis to vertical acceleration ratio is one which means that a radial velocity of 3 feet/sec would veer an object off at 45° angle. The

tentatively design standard for Tassel having a 500 foot cable system at 2 rpm provides approximately 1/6 g vertically and a 20% side coriolis acceleration. For example, under these conditions, water being poured into a glass 12 inches directly below the pitcher spout would miss the center of the glass by 2.4 inches. This could be rather disconcerting if allowance were not made.

It is believed that the tolerable level of Coriolis acceleration will be a deciding factor when determining what length cable system should be used. Dr. Thomas R. Davis, M.D. of the U.S. Army Medical Research Center states in Atlantic Monthly that "rotation creates an interesting but disturbing set of medical problems associated with the organs of balance. If a man or an animal is rotated and the axis of his vertibular apparatus is changed, as in nodding or tilting of the head, some wonderfully fantastic and highly disturbing results take place, similar to those we experience during a ride on a super roller coaster. Very few individuals can tolerate much of this. Some vomet, some manage to emerge with only a pale green complexion, and others have had to go to bed to recover.

Current research has done much to define the psychophysiology of the problem. The adverse effects of rotation vary greatly from one individual to another. Professional dancers and acrobats are the least effected. If rotation is necessary, there is some glimmer of hope, for it has been shown that animals and man have a fairly rapid ability to adapt to the effects of rotation."

ADDENDUM

The following two illustrations are from an earlier Convair report No. AZP-100, by F. D'Vincent, depicting a Two-astronaut space laboratory. These illustrations are included as an addendum because the Tassel design concept has been patterned after the Two-astronaut system.

In general, the same design philosophy exists for the two concepts. The laboratory, supplies, re-entry vehicle and astronauts are boosted into orbit as a unit, thus eliminating the need for orbital rendezvous. The depleted Centaur tankage is used as a counter-mass for providing centrifugal gravity in both designs.

Variations in detail design between Tassel and the Two-astronaut system are itemized as follows:

(1) Tassel orbits 3 men for a duration of approximately 3 weeks. The Two-astronaut system orbits 2 men for about 5 weeks.

(2) Tassel's design is based on a newly-developed re-entry capsule accommodating three. This new design features an access door on top of the capsule, increasing the capsule's usefulness as an all-purpose re-entry vehicle and its adaptability to various advanced space systems.

The Two-astronaut system employs a modified Mercury capsule design with a minimum of rework.

(3) Tassel requires that its re-entry capsule be inverted in orbit, simplifying access to the space cabin and allowing the capsule to be utilised as a separate room for sleeping. This is also very desirable from the safety standpoint.

The Two-astronaut system requires a tunnel between the capsule and the cabin for by-passing the capsule's heat shield. Because the Two-astronaut system's re-entry capsule is not intended to be inverted, the centrifugal gravity created by rotation acts in the wrong direction with respect to the capsule's top. The gravity force tends to throw the astronaut out of his couch, making the capsule unsuitable as a sleeping room. This also means that, prior to jettisoning from the laboratory, the astronauts must strap themselves in their ceiling couches.

FIG. 20 ASCENT TWO-MAN SYS. (REF. AZP-100)

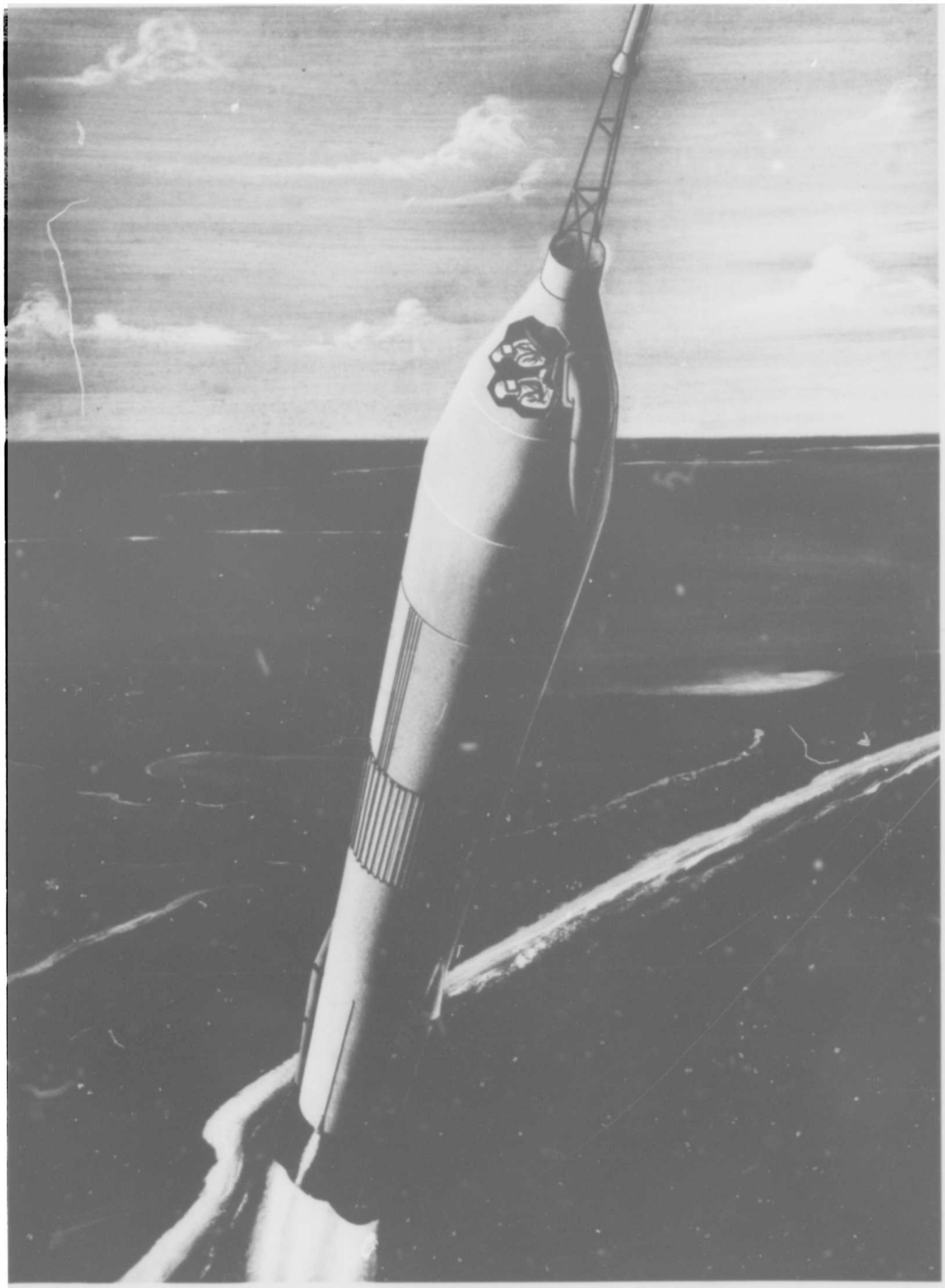


FIG. 21 ORBIT TWO-MAN SYS. (REF. AZP-100)